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A Layered Felsic Diatreme near Weolseong, Kyeongsang Nam Do, Korea

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Abstract: The Weolseong diatreme crops out about 28km south of Kyeongju City, Korea. The diatreme is a circular shaped volcanic vent, 1.2km in diameter, that formed subaerially, probably by phreatomagmatic (phreatoplinian) eruptions of Tertiary age. The rocks occupying the display well developed layering produced by base surge and proximal ballistic fall. Accretionary lapilli are a common component. The rocks comprise tuff breccia and fine-grained rock derived from the vent walls. This sequence has undergone subsidence of at least over 650m.

Most explanations for the presence of bedded tuffs at considerable depths within a volcanic pipe involve subsidence. Comparable amount of subsidence are recorded in many diatremes in other parts of the world.

The ore body is distinctly circular and funnel shaped in center of diatreme. The vent area of diatreme served as channel ways for the mineralized hydrothermal fluids.

INTRODUCTION

This paper describes a newly discovered bedded felsic diatreme revealed by diamond drilling (1982~1984) by KIER as part of an exploration programme for As-Zn ores in the Weolseong area, south of Kyeongju City, Korea. The results of the drilling programme indicate that As-Zn ores occupy the central part of the diatreme.

GEOLOGIC SETTING

Rocks exposed in the vicinity of the diatreme are sandstone of the Sayeonri Formation of Cretaceous age (Choi et al, 1980), ash flow tuffs of the Chisulryoung Volcanic Formation (Park and Kim, 1985), and intrusive hornblende granodiorite and biotite granite of Tertiary age. The diatreme cuts the hornblende granodiorite and is intruded by numerous dykes ranging in composition from diorite to granite. The silicic volcanic rocks of the Weolseong area, considered in early geologic reports to be lava or intrusives, comprise tuffs of the Chisulryoung Volcanic Formation (Park and Kim, 1985).

THE DIATREME

The diateme crops out near the Nokdong Ri, Weolseog, about 28km south of Kyeongju City. It displays a nearly circular shape with a diameter of 1.2km. It is well exposed at surface and drilling reveals that layered rocks extend to a depth of at least 650m. The exposed part is filled with a chaotic assemblage of blocks and finer debris drived from the Chisulryeong Volcanic Formation and from the granite wall rocks. Bedding is only rarely seen in contrast to the drilled section where the dominant layering consists of alternating fine and coarse beds (Fig. 3., Photo. 1.). The thickness of individual layers varies from a few centimeters to several meters, and the size of fragments displays vertical grading in individual layers. The layering dips gently toward the central part of the diatreme. In general, the layering of the diatreme dip inwards at 20°~45°. (Fig. 1.).

The diatreme contains a wide variety of rock

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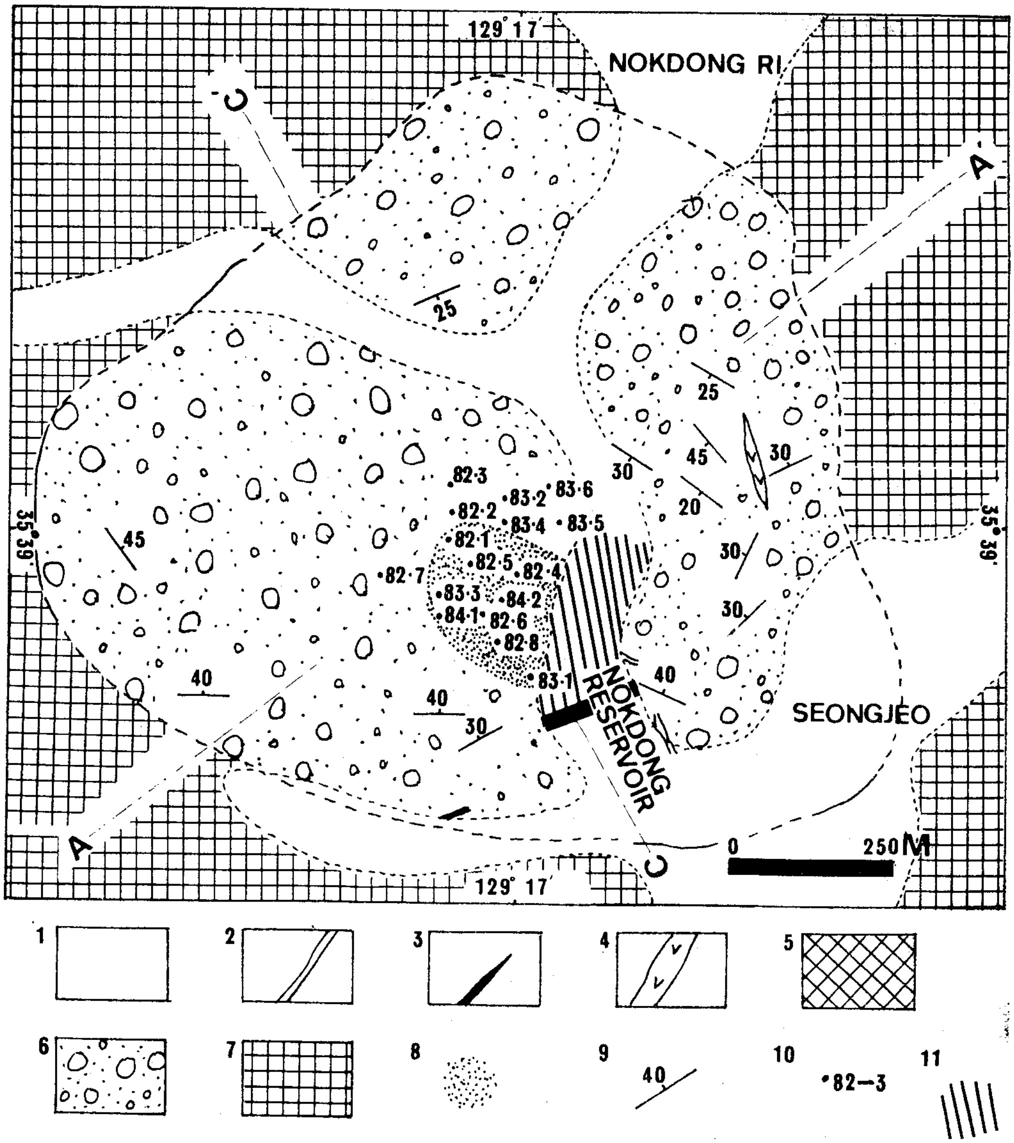
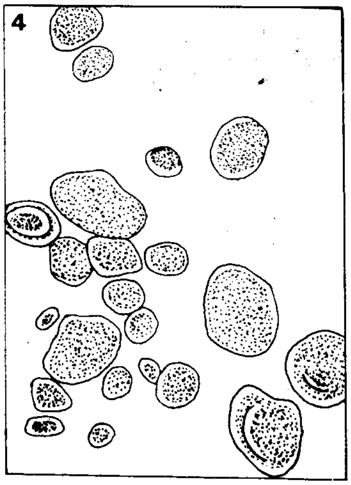


Fig. 1 Geologic map of diatreme area.
1; Alluvium, 2; Rhyolite, 3; Basalt dyke, 4; Leucocratic granite, 5; Diorite, 6; Diatreme, 7; Hornblende granodiorite, 8; Mineralized area, 9; Bedding, 10; Drill hole No. & site, 11; Reservoir

fragments including granite, welded tuff, rhyolite, basalt and dolerite. Welded tuff, granite and rhyolite together with mineral grains derived from these are the dominant constituents. Generally the clasts vary from angular to subrounded. Many have been slightly altered by hydrothermal processes (Photo. 2). Induration was affected by compaction and carbonate and clay cementation.

Coarse Beds

The most characteristic rock type in the drill cores consists of massive beds of coarse-grained, lithic clast-rich deposits which constitute 90% of the total thickness in most of the cores. The thickness of the coarse beds varies from 1 meter to several meters. This type of material also constitutes most of the surface exposure and is a remarkably heterogeneous deposit lacking internal



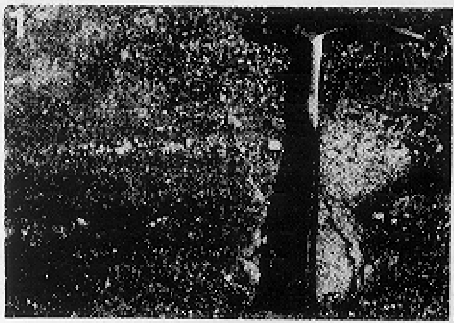
Explanation of photographs

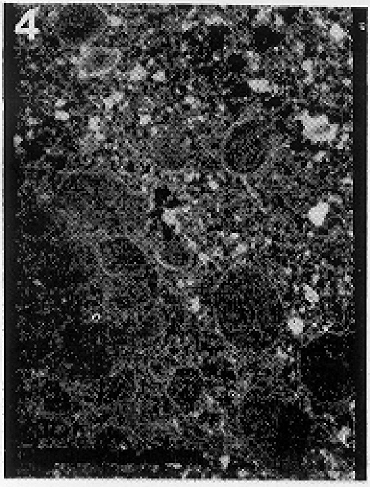
Photo. 1. Bedding in diatreme.

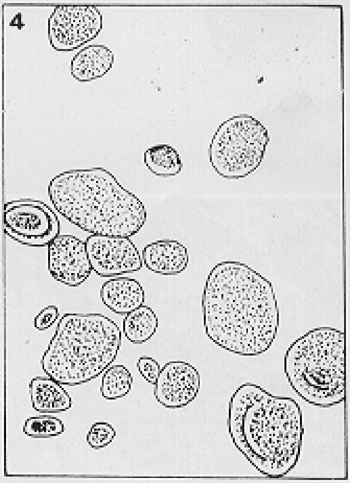
Photo. 2. Altered rock fragments in diatreme.

Photo. 3. Photomicrograph showing the rock fragment (micrographic granite) in coarse bed. (bar scale; 0.2mm)

Photo. 4. Photograph of tracing showing the 30% (weight) actcretionary lapilli and the numerous concentric layers (circular shap) in bore hole No 83-1, 434m below surface. (bar scale; 10mm)







Explanation of photographs

oto 1. Bedding in diatreme

Table 1 Modal composition of rock fragments in diatreme.

Rock	Rock fragments in diatreme															
Sample No	83-6-380	84-2-582	2	7	12	13	14	15	16	17	18	19	20	21	22	23
Quartz	16.0	23.8	17.5	21.7	25.8	20.9	17.3	22.4	11.3	19.7	20.5	31.0	16.7	13.5	23.4	17.9
K-feldspar	16.2	11.5	—	33.3	38.8	27.3	21.5	17.6	10.7	15.3	17.9	42.0	19.7	21.5	10.3	12.9
Plagioclase	59.8	60.9	82.5	45.0	32.8	47.9	59.6	55.7	70.6	64.7	59.7	27.0	59.3	60.7	60.1	65.3
Hornblende	1.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fe Ore	1.1	0.5	—	—	0.7	1.2	1.5	2.7	3.1	0.3	0.4	—	3.1	3.6	5.5	1.9
Chlorite	5.6	3.3	—	—	1.9	2.7	0.1	1.6	4.3	—	1.5	—	2.2	0.7	0.7	2.0
Q+Kf+Pl	92.0	69.2	100	100	67.4	96.1	98.4	95.7	92.6	99.7	98.1	100	94.7	95.7	93.8	96.1

stratification. Lithic fragments comprise as much as 70% of the rock. They range in length from less than 1cm to more than 10cm and decrease in abundance and size upwards in individual units. Basalt fragments are especially abundant in the lower part of the diatreme, and accretionary lapilli occur in the upper part in individual layers.

Under the microscope the rock displays a clearly clastic texture. Fragmented crystals of quartz and plagioclase and small lithic clasts are embedded in a matrix of finely comminuted quartz and feldspar dust.

Lithic clasts

The following lithic clasts have been identified in the coarse beds.

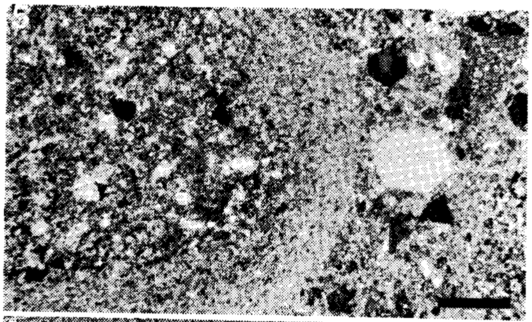
i) Basalt including aphyric types; some types are rich in a fine-grained Fe-oxide mineral.

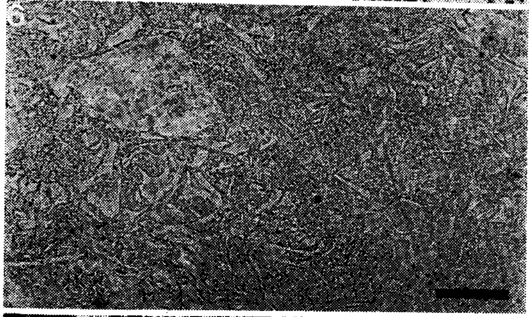
ii) Hornblende granodiorite. A dark grey, fine-grained rock, identical in texture and grain size to the hornblende granodiorite of the wall rocks. The modal analysis by point counting is shown in Table. 1, Fig. 5.

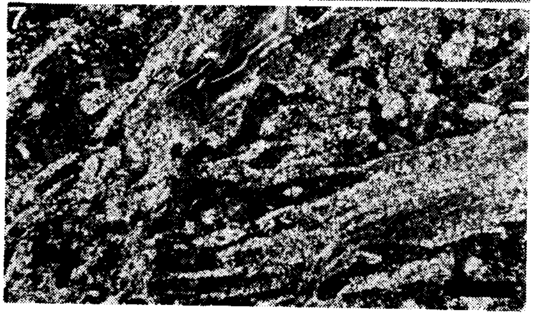
iii) Biotite granite. A medium to fine-grained rock with micro-graphic texture, the same as the marginal facies of a biotite granite in the Ulsan area (Photo. 3). The modal analysis by point counting is shown in Table 1, Fig. 5.

iv) Dolerite is fine grained and displays plagioclase spherulites.

v) Rhyolite is fine grained to glassy, flow banded on a micro scale and sometimes porphy-





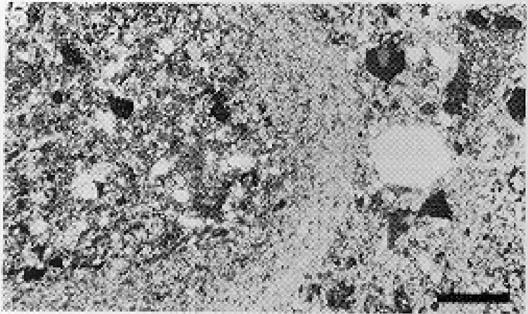


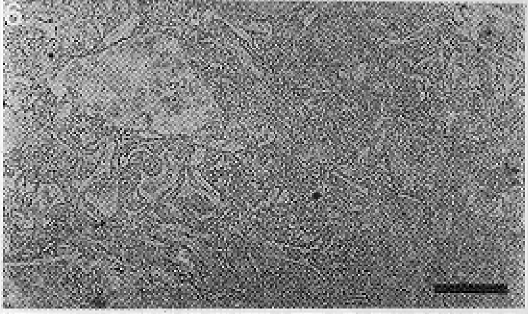
Explanation of photographs (Continued)

Photo. 5. Photomicrogaph of accretionary lapilli (circular shape on the left side in coarse bed. (bar scale; 0.2mm)

Photo. 6. Vitroclastic fabric in the fine bed. (bar scale; 0.2mm)

Photo. 7. Glassy pumice fragment in fine vitric bed. (bar scale; 0.2mm).





Explanation of photographs (Continued)

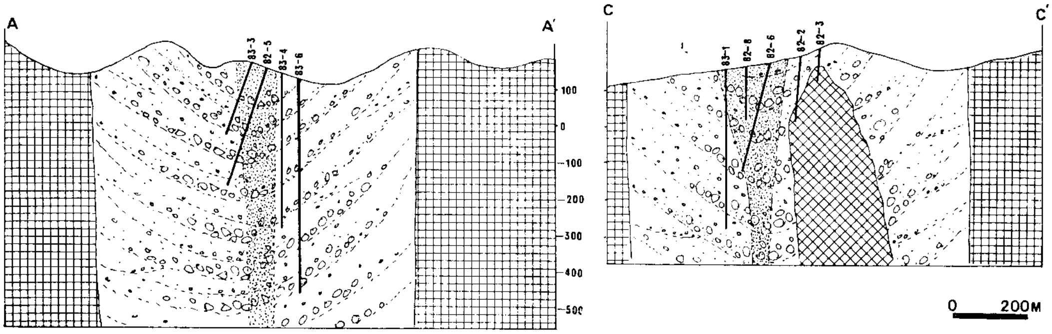


Fig. 2 Cross section of the diatreme, along line A-A', and C-C' in Figure 1. Legend as in Figure 1.

ritic.

vi) Welded tuff clasts display eutaxitic welding of both pumice fragments and matrix. The welded tuff includes fragments of basaltic rock but is itself of rhyolitic composition. Welded tuff fragments are larger than the average clast size for all lithic clasts in the diatreme. They are similar to the ash flow tuffs of the Chisulryoung Volcanic Formations and have probably not moved significantly in a vertical direction.

The rock fragments are generally little altered (Photo. 2). However, ferromagnesian minerals in basaltic rocks are commonly replaced by chlorite, epidote, and calcite and the feldspar of all rock types may be sericitized to varying degrees.

Accretionary lapilli

A conspicuous feature is the abundance of accretionary lapilli in a medium-grained matrix in the upper parts of the some layers in drill cores. They are only rarely seen at surface. The lapilli occur in the slightly coarser and broader bands with each lapilli showing a well-developed concentric rim (Photo. 4). These range from 5mm to less than 10mm diameter. Most were in the 5~7mm range and the larger lapilli generally contain several concentric shells (Photo. 4). The cores of the lapilli are composed of material of slightly smaller grain size but similar composition to the rock matrix and include rock and mineral fragments and pyrite (Photo. 5). The well-stratified parts of the Weolseong dia-

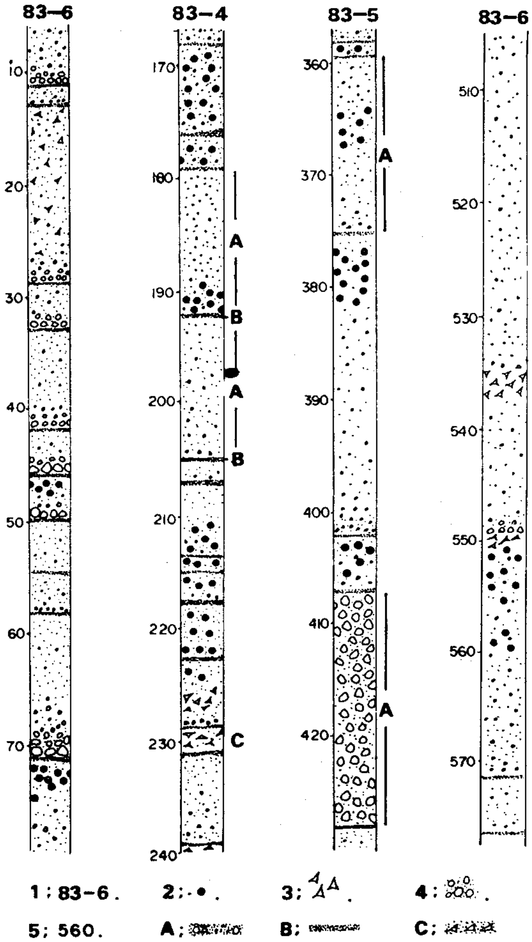


Fig. 3 Core logging data in diatreme.

1; Drill hole No,
2; Accretionary lapilli,
3; Pumice and shards
4; Lithic clasts,
5; Depth.
A; Coarse zone (Lithic clast rich zone),
B; Fine lithic zone,
C; Fine vitric zone.

treme sequence are characterized by up to about 30% by weight of accretionary lapilli, which all exhibit a typical concentric internal structure (Photo. 4).

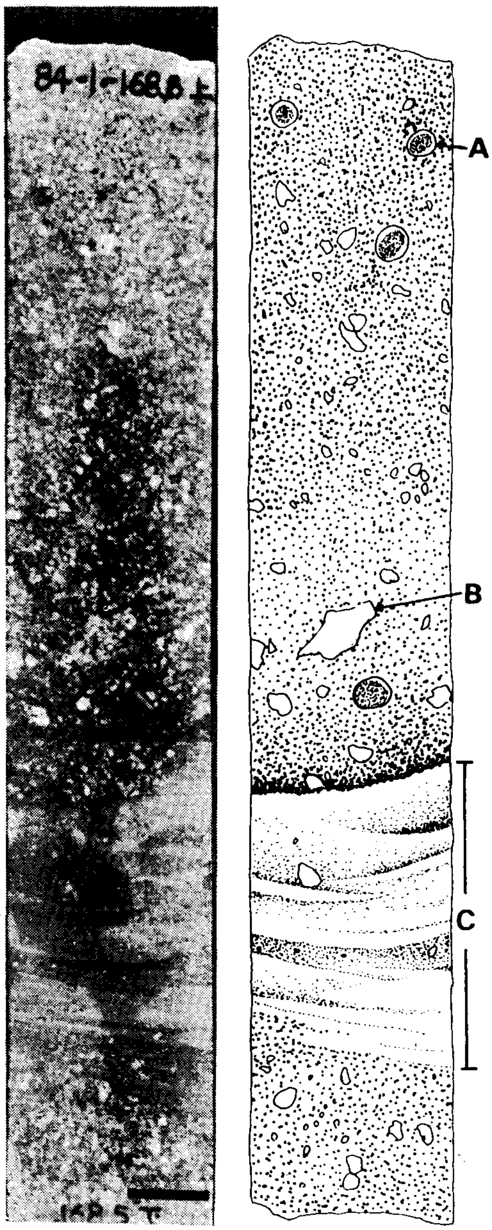


Fig. 4 Photographs and tracing cross bedding, accretionary lapilli and lithic clast rich layer (coarse bed) in bore hole No 84-1, 168.5m below surface. (bar scale; 1cm)

A; Accretonary lapilli,
B; Lithic clast,
C; Cross bedding.

Groundmass

The groundmass (matrix) of coarse beds occupying the diatreme consists of lithic fragments, broken and fractured crystals, and very fine-grained matrix material. The majority of the mineral grains consist of plagioclase, quartz or K-feldspar. Ferromagnesian minerals are partly altered to chlorite, sericite and calcite. Pyrite occurs in euhedral crystals scattered throughout the fine matrix (Photo. 5).

Fine Beds

Thin beds of well-bedded, fine-grained or pumiceous tuff occur above each of the coarse beds (Fig. 3).

These comprise;

i) Lithic ash of rhyolitic composition comprising mineral and rock fragments in beds less than 5cm to 20cm thick. Cross bedding (Fig. 4) is only rarely seen in the drilled section and indicates that part of the ejecta were deposited by base surge flows during eruption (Sheridan and Updike, 1975).

ii) Vitric ash of rhyolitic composition comprises mostly colorless pumice fragments and shards with angular to subangular forms. The shards are generally of equant or pyramidal form. Pumice fragments have straight to slightly curved vesicles (Photo. 6. 7). The matrix material of the ash, with an approximate mean grain size of 0.01mm, is mostly angular.

ROCKS INTRUDING THE DIATREME

Diorite

A small body of diorite, which does not crop out at surface, was discovered by drilling (Fig. 2). This rock intrudes the center of the diatreme and displays chilled margins. It is medium-grained, grey and comprises hornblende and plagioclase with a little quartz, K-feldspar and magnetite and lesser amounts of sphene, apatite and zircon. Distinction of K-feldspar was made

Table 2 Modal composition of dioritic rock in bore core.

Rock name	Diorite										
Sample No	83-1-57	84-4-204	83-2-338	82-2-258	82-3-50	83-2-294	82-2-184	82-2-173	82-2-178	82-3-77	83-1-57
Quartz	2.0	2.1	7.5	4.6	8.9	7.53	13.3	2.9	4.9	4.2	2.1
K-feldspar	12.5	9.4	10.0	6.1	8.4	6.0	1.7	8.9	4.8	6.0	14.6
Plagioclase	71.0	64.5	70.5	60.95	64.8	56.9	70.7	66.1	71.7	58.3	83.3
Hornblende	10.0	14.5	4.0	18.1	9.7	7.97	12.3	15.7	14.5	27.9	—
Fe Ore	3.0	—	1.5	4.25	2.2	—	—	1.1	3.1	2.3	1.0
Apatite	—	0.4	—	1.3	1.1	2.0	—	1.9	—	—	—
Sphene	1.5	9.1	—	—	—	—	—	—	—	—	—
Chlorite	—	—	6.5	4.7	4.9	9.61	0.9	1.4	1.8	2.6	—
Q+Kf+Pl	85.5	76.0	88.0	71.65	82.1	70.43	85.7	77.9	80.4	68.5	100

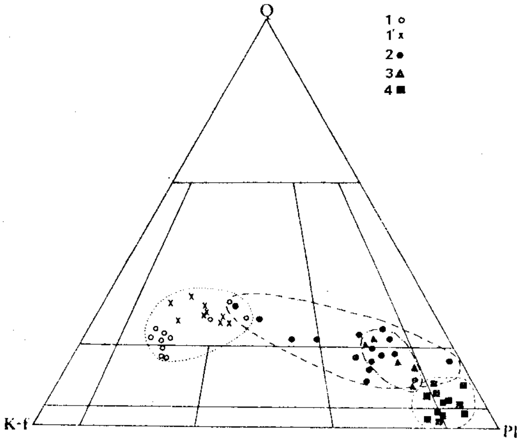


Fig. 5 Modal Q-Kf-Pl diagram.
1; Biotite granite (data from Park, 1980),
1'; Biotite granite (data from Choi, 1984),
2; Lithic clasts in diatreme,
3; Hornblende granodiorite,
4; Diorite.

by a staining method (Ruperto et al., 1964). Hornblende is pleochroic in shades of brown, and the size of the euhedral to subhedral crystals is up to 2.5cm. The modal composition of this rock can be determined in stained sections (Table 2, Fig. 5). As shown in Fig. 5. the intrusion is classified as diorite in a broad sense, ranging from diorite to quartz diorite.

Leucocratic Granite Dyke

This is lens-like intrusion about 3m by 20m in plan. It is typically medium- to fine-grained, pinkish colored, with porphyritic glanular to aplitic texture. Faintly zoned plagiclase forms equant cystals in association with glanular quartz and interstitial alkali-feldspar. Boitite and hornblende are the mafic constituents. Plagioclase occurs mainly as phenocrysts partly replaced by sericite. The K-feldspar is a micrographic intergrowth with quartz and is present in the groundmass. Accessory and secondary minerals are the same as in the Ulsan Granite body.

Rhyolite Dyke

This dyke which cuts the diatreme, is exposed in road cuts, is discontinuous, and ranges in width from 1m to 5m; it trends south-west and dips 45° to the north-west. It displays excellent flow-banding in a dense, glassy rock which displays spherulitic texture and quartz phenocrysts under the microscope.

Hornblende Basalt Dyke

This dyke cuts the diatreme and the ore body, is thin, continuous, and occurs both within and outside the diatreme. This dike is fine-grained and have lamprophyric to hypidiomorphic-granular texture. Sparse plagioclase and hornblende phenocryst occur in dike. Very fine grained (chilled) margins have been observed on some of the fine grained dikes.

DISCUSSION

The term "DIATREME" was originally used at end of 19th century to describe a volcanic pipe or vent filled with tuff or tuff-breccia, thought to be produced by gas-rich volcanic activity (McDonald, 1972, p. 378). They are round to elliptical in horizontal cross section, and tens or hundred of meters in diameter. They have a nearly vertical axis, and persist to depths of hundreds or thousands of meters. They contain intensely fractured rock with a particle size ranging from micron to several meters. The rock fragments may be either heterogeneous or homogeneous. The largest blocks and lapilli generally occur low in the sequence. The pipes are fracture controlled, explosions being a major but not the sole cause of fragmentation of the rock. Many diatremes display all of the following characteristics (1) a parental magma that is mafic-alkali or ultramafic-alkali composition, (2) major subsidence of the infill, (3) large xenoliths that have descended hundreds or thousands of meters within the pipe from their previous stratigraphic levels, (4) xenoliths that have been brought up from great depth.

Hughes (1982, p. 50-57) noted that some hypabyssal rocks show evidence of diatreme emplacement, notably lamprophyres, carbonatite, and some members of the appinitic association. Futhermore, diatreme activity is not confined to these classes of rocks, but characterizes in addition near surface igneous activity of intermediate and acidic compositions.

There are two major genetic types of diatreme. The first is derived from fluid driven from deep within the earth's mantle, basic or ultrabasic in composition, and producing kimberlites and carbonatites. (Hern, 1968; McGetchin et al., 1973; Shoemaker et al., 1962; Woolsey et al., 1973; McCallum et al., 1976; Lorenz, 1975; Wilshire, 1961). The second type, and the one of interest here, consists of pipes formed by pheratomatic explosions.

Early studies of maars and diatremes were by Cloos (1941), Shoemaker et al. (1962), Woolsey et al. (1973), and McCallum et al. (1976). Recently Lorenz (1971, 1975, 1979) has studied diatremes in the Swabian Alb, Germany, and has discussed the origin of an extensive diatreme field in Montana. Although these are ultrabasic pipes, he notes many features similar to phreatomagmatic diatremes. Hearn (1968, p. 624) stated that repeated eruption alternated with subsidence to keep the conduit filled to a level near the surface. Lorenz (1975) also believed that some of the ultra-basic kimberlite diatremes are identical in processes of formation to the basic to acidic phreatomagmatic maars and diatremes.

Phreatomagmatic activity results from the interaction of magma with surface or near-surface water (Schminke, 1977; Sheridan and Wohletz, 1981). Hydrovolcanic (including phreatomagmatic) processes occur in volcanic structures of all sizes, ranging from small phreatic craters to huge calderas. The most common hydrovolcanic edifice is either a tuff ring or a tuff cone, depending on whether the surges were dry (superheated steam medium) or wet (condensing steam medium). Phreatomagmatic eruptions are initiated at depths less than the critical pressure of water, as shallow as 100 to 200m or even less. The depth to which they propagate depends upon the supply of water and magma. As determined from out crops and drill hole data, it is proposed that the Weolseong diatreme formed by silicic phreatomagmatic activity (called phreatoplinian by Self and Sparks, 1978).

In common with many diatremes (Self et al., 1980), the Weolseong diatreme is believed to have been localized by a regional fault zone. Although no direct observations are available, a permeable fault zone would provide ideal conditions for descending ground water to encounter ascending bodies of magma.

The coarse zones (beds) in the Weolseong diatreme are dominated by a coarse, poorly stratified and poorly sorted facies (Fig. 3) but contain interbeds of a fine, silty and well stratified facies (Fig. 3). The poorly stratified parts correspond to the explosion breccia of Wohletz and Sheriden (1983) and the proximal air fall deposite at Mount St. Helens (Waitt et al., 1981) and accumulated mainly by ballistic fall of ejecta.

Not all diatreme- or maar-type volcanoes contain xenoliths of deep-seated rocks. For example, the alkali basalt diatremes of the Hopi Butte of northern Arizona contain only altered granite fragments apparently derived from the uppermost parts of the basement. The Minette diatreme of the Navajo Reservation (William, 1936) contains only crustal fragments. The Ubehebe crater in Death Valley, California, contains no deep seated rocks, although some rounded crystalline xenoliths of granitic composition, apparently derived from the Pre-cambrian rocks exposed beneath the associated lava, have been reported (Roddy, 1967). The Weolseong diatreme is therefore similar to the latter example in that it contains no deep-seated xenoliths. The accretionary lapilli unambiguously testify to a subaerial origin for the coarae beds and probably originated as wet volcanic particles around water globlues. The accretion process could occur either during air fall from the eruption clouds or in base surge clouds moving across the groud surface (Lorenz, 1974; Self and Sparks, 1978). Moore and Peck (1962) determined that accretionary lapilli were formed by the accretion of moist ash in eruptive clouds falling as mud pellet rains. The accretionary lapilli in the Weolseong diatreme occur with a medium to coarse sized matrix corresponding to proximal air fall deposits in Mount St. Helens (Waitt et al, 1981) and proximal ash fall deposits in Sete Cidades caldera, Sao Miguel, Azores (Booth and Walker, 1978).

Accretionary lapilli consist of numerous concentric layers (Photo. 4) of the fine ash formed as the aggregate tumbles during growth, usually proximal to the vent (Wohletz et al, 1983). Proximal deposits ranging from surge beds to staratified ash and layers with accretionary lapilli are common. Wet surges typically form thick, near-vent accumulations that are strongly by secodary minerals formed in the warm damp ash shortly after eruption. The beds are generally thick, massive to planar types with indistinct stratification (Sheridan et al, 1983). The presence of accretionary lapilli and low angle cross beds, and the lack of sag structures beneath large fragments in the well stratified beds of the Weolseong diatreme, suggest they originated as low-temperature base surge deposits. Base surge deposits are ubiquitous products of phreatomagmatic activity (Moore, 1967) and deposits similar to those at Weolseong have been described by Sheriden et al (1983).

Many diatremes contain bedded pyroclastic material which must originally have been deposited at much higher levels in the pipes than their present locations. Francis (1971) postulated a minimum of 500m of subsidence for bedded tuffs in the Fife vents of Scotland, and estimates by Cloos (1941), Lorenz (1971), Hearn (1968), Sillitoe et al (1984), and Nysteun (1975) of subsidence in diatremes in Germany, Montana, U.S.A., Papua New Guniea and Norway, are 300m, 700m, 1,280m, 1,000m, and 1,000~1,500m respectively.

Various processes of subsidence have been considered. Francis (1962, 1971) discussed processes of subsidence both with and without the development of ring fractures for bedded tuffs in the Fife vents. Many diatremes show no evidence of ring fractures and wallrock beds are essentially undisturbed (e.g. in New Mexico and Arizona—Williams, 1936; Shomaker, 1956; McBirney, 1959; Swabia, Germany—Cloos, 1941). However, subsidence of bedded tuffs along ring fractures in the Hoofer Hof and Hausplatz structures of the Saar-Nahe area, Germany (Lorenz,

1971) and Black Butte diatreme, Montana, U.S.A. (Hearn, 1968) is of the order of 1,200 to 1,300m. Hearn (1968, p. 622) postulated a mechanism in which repeated eruption and air-fall tuff accumulation alternated with subsidence keeping pipes filled to near surface levels, each diatreme being filled by its own eruptions. Most of the bedded mass then subsides concurrently with central eruption, and marginal drag accentuates the inward-dipping saucer shape.

The surface expression of the Weolseong diatreme has been destroyed by erosion but subsidence of at least 650m can be inferred. The bedded breccia in the lower deposits contains accretionary lapilli and must have subsided into the diatreme from the surface. This bed is found at about 650 m below the present surface.

CONCLUSIONS

Briefly stated, the sequence in the formation of a diatreme is as follows; (1) A magma body is emplaced at rather shallow depth. (2) A cupola rises along a zone of weakness. (3) The magma encounters a voluminous supply of water at some depth shallower than the critical point of water. (4) Water flashes to steam with an intense explosion occurring. (5) Intense pressure is exerted radially, opening fractures. (6) Repeated smaller-scale explosions occur at very short intervals. (7) A steep-walled crater forms, called a maar, if below the surrounding land surface. (8) Progressive collapse of the crater rim occurs on ring faults, with large blocks subsiding into the crater. (9) The center of fuel the explosion, as long as adequate water is avaiable. (10) Post-eruptive subsidence of the breccia filling may occur on ring faults. (11) Hydrothermal solutions may migrate up through the vent.

It is believed that this sequence of events can explain the features of the Weolseong diatreme, the tuff and tuff breccia being erupted subaerially, accumulating in or around the vent at surface, subsequently subsiding into the vent to at least 650m depth.

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層狀型의 珪長岩質 DIATREME

朴 箕 和*·金 善 億*

要約：慶州 南部 2.8km 지점에는 치술령 화산암층이 분포하며, 이 화산암층 보다 후기에 분출 형성된 diatreme이 있다. diatreme은 지름이 1.2km의 원형의 화구로서 화산쇄설물로 충진 되어 있다. 이 화산 쇄설물은 proximal ballistic fall deposits로서 층리를 보여주며, 각 층은 상당히 두껍고 특징적으로 많은 양의 accretionary lapilli가 함유되어 있다. 이러한 특징은 시추에 의해 지표 하부 650m가지 확인되었다. 이러한 특징으로 보아 diatreme은 규장질 magma에 많은 양의 물이 유입되는 환경에서 연속인 분출 활동을 하였음을 의미하고, 화산 활동 기간 중에 연속적으로 화산쇄설물이 퇴적 및 침강 하였음을 의미한다.

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