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Ash-Flow Tuffs of the Chisulryoung Volcanic Formation and Associated Welded Tuff Instrusion, Weolseong District, Southern Korea

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Abstract; The Chisulryoung Volcanic Formation comprises a thick sequence of pyroclastic flow deposits. Six members are distinguished, each representing separate flow units, comprising weakly to intensely welded acidic tuffs. A stock of welded acidic tuff, 1 km in diameter, intrudes hornblende granodiorite and sediments of Late Cretaceous age and the lower part of the Chisulryoung Volcanic Tuff Formation and may represent the vent through which the upper flows of the Chisulryoug Volcanic Formation were erupted.

INTRODUCTION

The volcanic rocks of the Weolseong area have been investigated as part of a Korea Institute of Energy and Resources (KIER) exploration programme for As-Zn ores. Field investigations were carriod out between 1982 and 1984 and included detailed geological mapping at 1:25,000 and 1:5,000 scales and an extensive diamond drilling programme which resulted in the discovery of an ore body within a volcanic diatreme (Park, 1984). This account describes the extrusive volcanic rocks of the area and an associated plug of intrusive welded tuff situated to the W of the mineralized diatreme (Fig. 1). An account of the diatreme is currently in preparation.

The Weolseong area, Southern part of Kyeongju City, lies within the Southeastern part of the Cretaceous Kyeongsang non-marine basin. The sediments of the basin are overlain by basic, intermediate and acid volcanics locally interdigitated with sediments. The regional stratigraphy established by Tateiwa (1924) has been used, with only slight modification, by most subsequent workers in the area during the last 50 years (eg. Lee and Kang, 1964; Park and Youn, 1968; Lee and Lee, 1972). Researchers from KIER have made a special study of the sediments in the area (Choi et al, 1980), and Lee (1980) has studied the petrochemistry of the granitic rocks of the Eonyang and Ulsan areas. The volcanic rocks, however, have received little attention.

In the Weolseong area the extrusive volcanic rocks comprise a thick sequence of pyroclastics. In early geological reports these were considered to be either lavas or intrusives but the current investigation reveals them to be, predominantly, variably welded pyroclastic flow deposits.

CRETACEOUS SEDIMENTARY ROCKS

Sedimentary rocks of the Weolseong area comprise mudstones, sandstones, tuffaceous sandstones and conglomerates. The sequence has been divided into the Guyoungri, Sayeonri and Joilri Formations (Choi et al, 1980), the contrasting lithologies reflecting deposition in a variety of fluvial, alluvial and lacustrine environments. In the study area mudstone of the Sayeonri Formation predominate and lie immediately beneath the volcanics. Intrusions of granodiorite and biotite granite yielding K-Ar ages ranging

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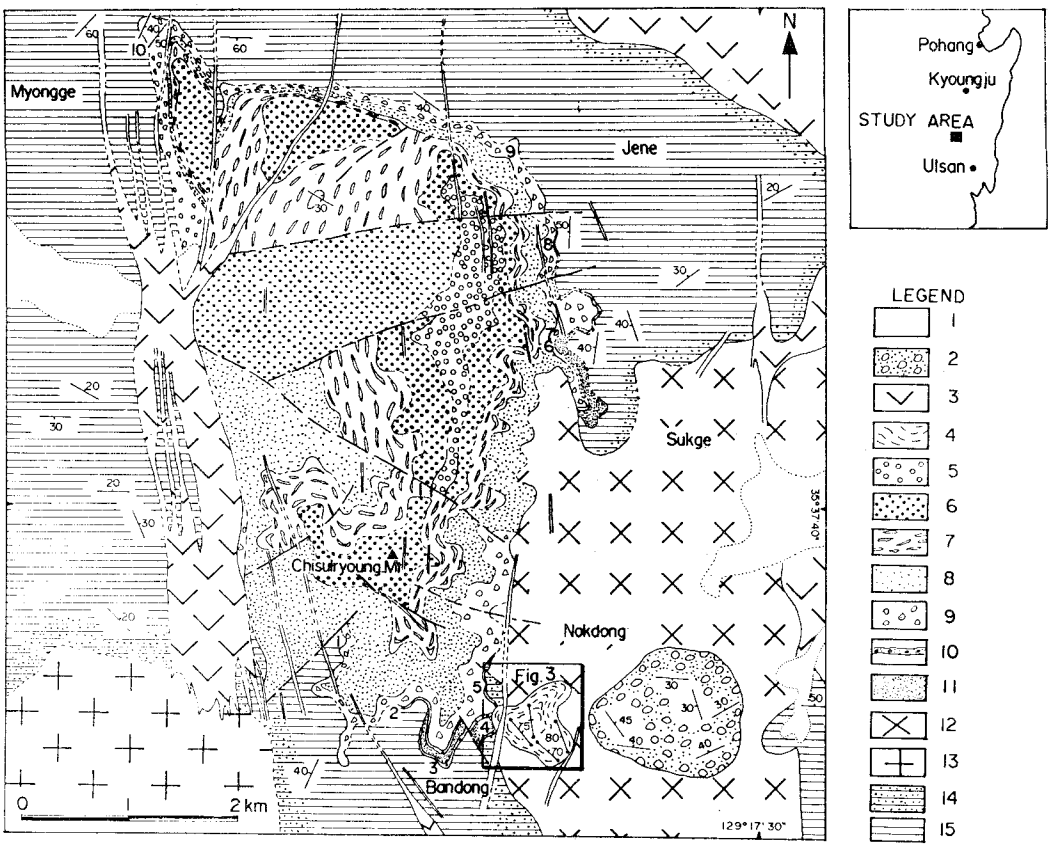

Fig. 1 Generalized geologic map of the Chisulryoung Volcanic Formation of the Weolseong district. Inset map shows the location of the district.

1; Aluvium, 2; Diatreme, 3; Biotite Granite, 4; Intrusive Welded Tuff, 5; Lithic Tuff Breccia (6th Member), 6; Pumice-rich Block, Lapilli and Ash-flow Tuff (5th Member), 7; Welded Ash-flow Tuff (4th Member), 12; Hornblende Granodiorite, 14; Hornfels, 15; Sayeonri Formation.

from late Cretaceous to early Tertiary (Lee, 1980) intrude and locally metamorphose (hornfels) the sediments.

THE CHISULRYOUNG VOLCANIC FORMATION

The Chisulryoung Volcanic Formation forms a discrete outlier of pyroclastic rocks, about 6 km long and 3km wide, extending northwards from the summit of Chisulryoung Mountain and from highest ground in the area. A total thickness of over 500m of pyroclastic rocks are present. The formation comprises mainly densely to weakly welded acidic ash-flow tuffs which have been divided into six members according to their crystal content, variations in clast size and type, and degree of welding. Individual members vary in thickness across the crop (Fig. 2) and a preliminary study of isopach maps of individual members indicates locally abrupt thickness changes across linear features suggestive of penecontemporaneous faulting.

The base of the formation rests variously on non marine sediments of the Sayeonri Formation and on intrusive hornblende grandiorite of late Cretaceous or Tertiary age (?) (Lee, 1980) intrusive into the Sayeonri sediments. Biotite

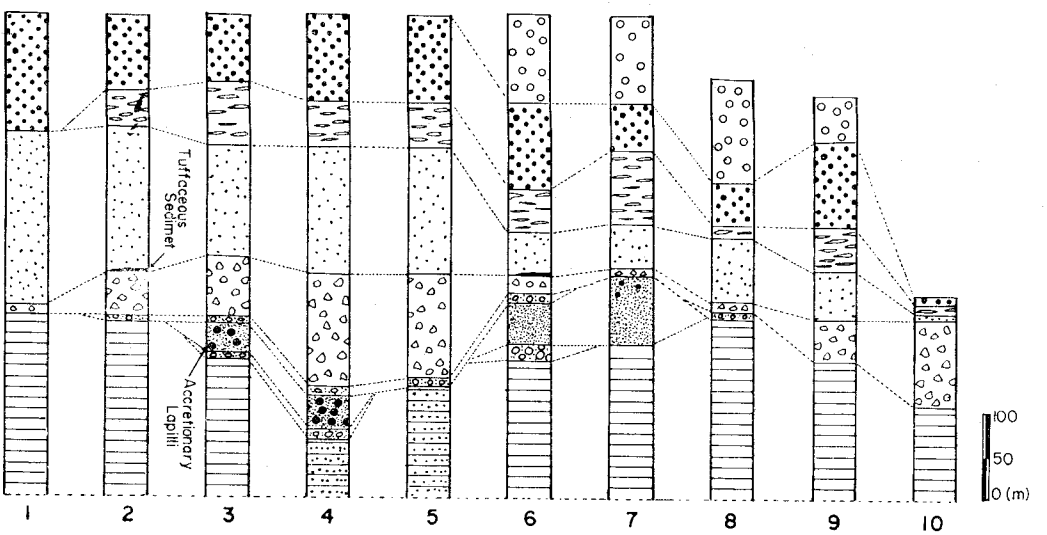

Fig. 2 Correlation of the ash flow tuffs. (Legend as in Fig. 1)

granite of Tertiary age (Lee, 1980), however, intrudes the Chisulryoung Volcanic Formation which is therefore either of latest Cretaceous or early Tertiary age.

The 1st Member- Accretionary Lapilli Tuff

The lowest member of the Chisulryoung Volcanic Formation comprises a fine grained matrix of ash with lithic fragments, crystals, pumice and accretionary lapilli. The member, up to 60m thick, extends from the Bandong area in the south through the Nokdong area to the Sukge area in the north (Fig. 1), the thickness gradually decreasing from SE to NW.

The fine matrix of the tuff is brown to yellowish brown and consists chiefly of altered ash. Shards are less than a few mm long and are generally replaced by axiolitic alkali feldspar. Angular lithic fragments 0.1 to 5mm in diameter, constitute up to 5% of the rock. The lithic frament are principally of acidic and basic lava and sedimentary rocks. They are numerous in the SE, near the intrusive welded tuff (Fig. 1), but, apart from pumice, fragments of all kinds become exceedingly rare to the N and W in the Sukge and Bandong areas.

Phenocrysts are mainly of fragmented resorbed plagioclase and quartz, but also include biotite, sphene and magnetite (Fig. 3-2). The plagioclase (albite-oligoclase) is polysynthetically twinned, and in the Nokdong area compositionally zoned. K-feldspar and quartz are less abundant than polgioclase and generally occur as subhedral to euhedral crystals. Quartz, K-feldspar and plagioclase crystals are rarely more than 5 mm long. The crystal and lithic fragments are consistently larger and more abundant in the SE near the intrusive welded tuff.

Pumice fragments make up less then 10% of the rock. They are most abundant in the SE, in the Sukge area, where they show flattening due to welding (Fig. 3-3).

Accretionary lapilli are restricted to the Nokdong and Sukge areas. In the Nokdong area, they form the most distinctive feature of the lst member, and are both larger and more abundant than in the Sukge area. They are ellipsoids generally 5 mm by 7 mm, but some attaining 2 cm in largest dimension (Fig. 3-1). They are commonly flattened, probably due to post depoitional compaction. They have the same greenish grey colour as the tuff in which they

occur, although on outcrop surfaces the concentric rims are white weathered.

The lapilli commonly consists of a core of ash, similar to that of the enclosing tuff, rimmed by finer grained ash. Some of the lapilli have as many as three concentric zones around their cores indicating repeated accretion before deposition from the ash cloud. The outer rims of the lapilli contain fibrous micaceous material probably representing devitrified vitric dust.

Conglomerate

Locally a conglomerate up to 10m thick overlies the lst member. It consists of a well cemented arkosic matrix containing unsorted boulders, cobbles, and pebbles of lava, hornblende granodiorite and sandstone. Most fragments are subrounded to rounded. The conglomerate occurs as a number of discontinuous lenses (Fig. 2), probably reflecting filled in paleochannels, and indicating an erosional break between the eruption of the lst and 2nd members of the Chisulryoung Volcanic Formation.

The 2nd Member- Bedded Tuff

The second member, up to 60 m thick, thins gradually northwards. Locally, as in the Sukge area, it is overlain by thin tuffaceous sediments. The member comprises a massive to well bedded (Fig. 3-4) fine grained tuff with an average grain size of about 1 mm. Beds tend to thin, are laterally discontinuous and show slight grading. In some areas, bedded tuff passes laterally into massive tuff.

The tuff is composed mainly of plagioclase, K-feldspar and quartz crystals, curved biotite flakes and minor amounts of shards, pumice, lithic fragments and opaque minerals. Quartz crystals and lithic fragments are consistently larger and more abundant in the SE near the intrusive welded tuff pipe (Fig.1). The shards are less than 1 mm in length and generally replaced by axiolitic K-feldspar.

The 3rd Member- Crystal-rich Welded Ash-Flow Tuff

The 3rd member is up to 70 m thick and thins gradually northwards. It comprises weakly to densely welded, crystal-rich ash flow tuff consisting of feldspar and quartz phenocrysts in a matrix of devitrified glass shards and collapsed pumice fragments. It contains fragments of red shale and rhyolite (Fig. 3-5). Grain sizes range from 3~5 mm.

Crystals comprise from 5~30% of the rock and are mainly broken and resorbed plagioclase (50%), K-feldspar(20%), quartz(25%), together with less than 1% each of biotite, Fe oxides, apatite, sphene in a groundmass of devitrified shards and pumice.

This member is laterally more extensive than the first two members of the Chisulryong Volcanic Formation. Except for decreasing thickness to the NW, it shows little lateral variation but it displays a gradual upward decrease in the content and size of K-feldspar, plagioclase, and lithic fragment, and a corresponding increase in quartz, axiolitic shards and recrystallized pumice.

The 4th Member- Welded Ash-Flow Tuff

The 4th member of the Chisulryoung Volcanic

Explanation of Fig. 3

1. Accretionary lapilli showing the concentric rim (bar scale: 2cm)
2. Photomicrograph of 1st member tuff near the Nokdong showing intensely resorbed quartz phenocryst within axiolitc shard rich matrix (bar scale: 0.1mm)
3. Extaxitic texture of 1st member, near the Sukge (bar scale: 0.1mm)
4. The 2nd member (Beded tuff) showing the bedding
5. Vitroclastic fabric in the lower part of the 3rd member, near the Sukge (bar scale: 0.1mm)
6. The glassy fragments in the upper part of the 4th member showing the slightly welding (bar scale: 0.1mm)

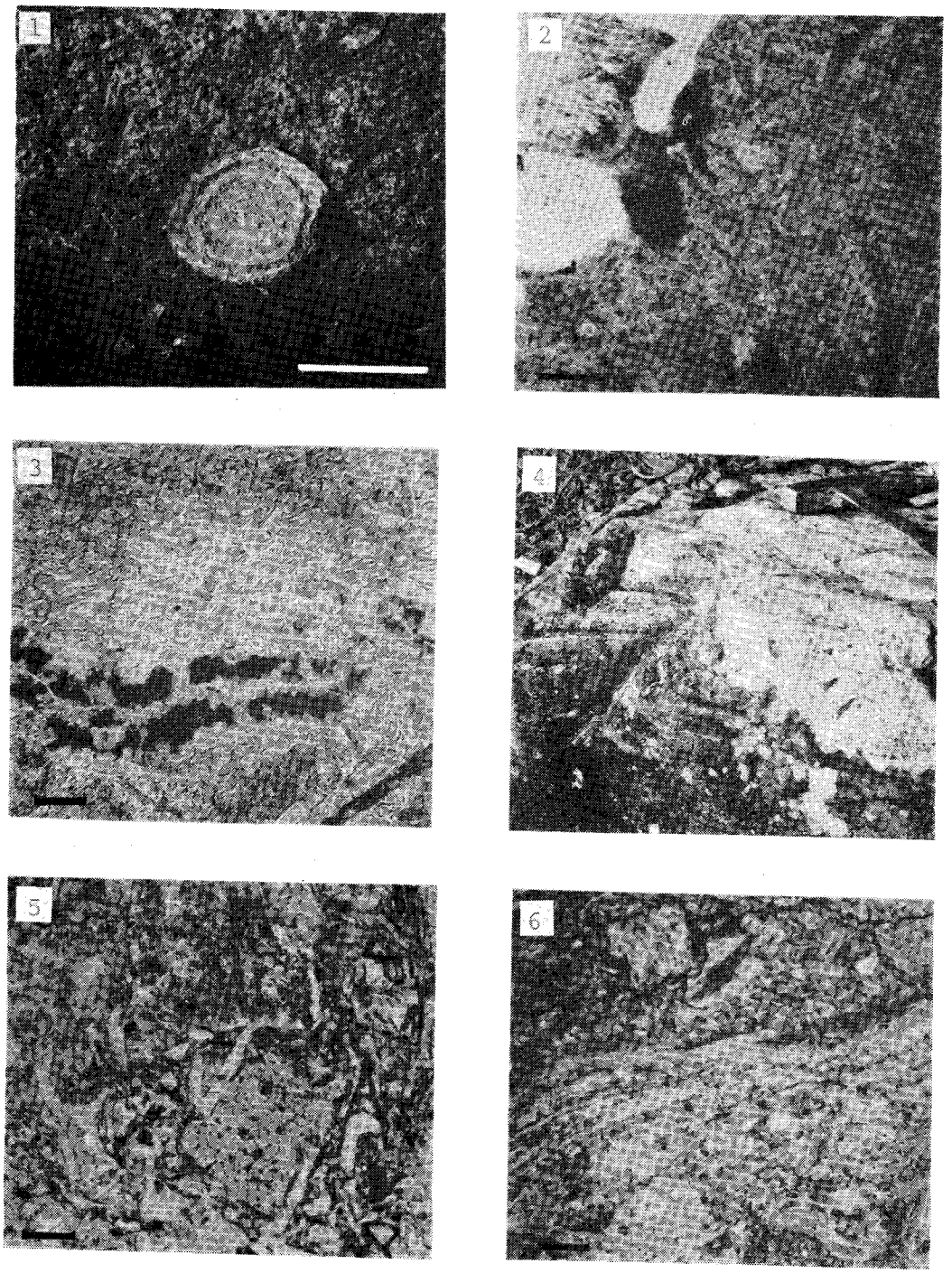

Fig. 3 photographs of volcanic formation.

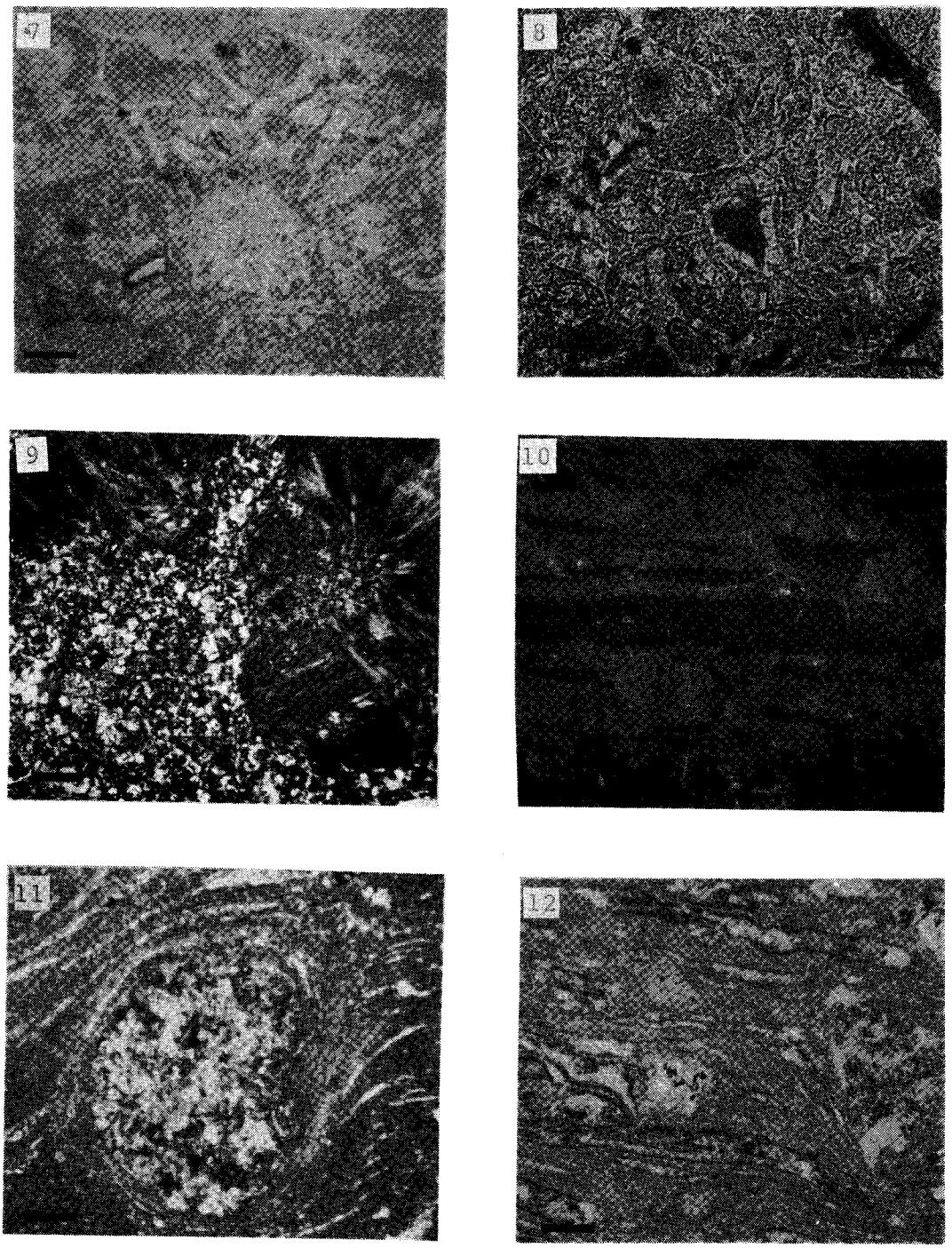

Fig. 3 Photorgaphs of volcanic formation(continued).

Formation is a 70m thick, crystal poor, densely welded tuff that was emplaced on top of the 3rd member. It forms a distinctive unit characterized by extremely flattened black glassy fiamme up to 10 cm long. The tuff matrix displays well developed eutaxitic and axiolitic textures and is composed predominantly of glass shards and pumice with minor amounts of lithic fragments and crystals (Fig. 3-6).

The lithic fragments, principally of acidic lava, are numerous only near the base of the tuff, and both crystal and lithic fragments are exceedingly rare in the upper part of the tuff. Shards and pumice, however, increase both in abundance and size in the upper part of the unit.

The groundmass consists of collapsed and devitrified shards and pumice fragment and the upper part of the tuff consists mainly of densely welded and axiolitic shards in a red devitrified matrix.

The 5th Member - Pumice-rich Block, Lapilli and Ash-Flow Tuff

The 5th member tuff, up to 70m thick, is massive, light grey to pinkish, mostly weakly welded, pumice-rich and contains phenocrysts of resorbed quartz and plagioclase together with lithic fragments in a groundmass of collapsed and devitrified shards. The pumice is of lapilli and block size, and is more coarsely recrystali zed than the shards and matrix (Fig. 3-7).

The tuff grades upward from its base, rich in crystal and lithic fragments, to its top, rich in shards. Overall the tuff contains less than 1% phenocrysts, most of which are plagioclase and quartz, biotite. Pumice fragments are more abundant than in the 4th member and are light grey to pinkish in colour. The groundmass of the pumice fragments is aphanitic, consisting of cryptocrystalline and spherulitic, axiolitic or fibrous feldspar and quartz.

The 6th Member-Lithic Tuff Breccia

The 6th member, up to 100m thick, contains abundant lapilli and block size rhyolite fragments within a devitrified and spherulitic groundmass of collapsed shard and pumice fragments (Fig. 3-8, 9). The rhyolite fragments comprise as much as 30% of the rock and range in length from less than 5 cm to more than 10cm. They decrease in abundance and size upwards.

Eruption history of the Chisulryoung Volcanic Formation

Eruption of the pyroclastic rocks of the Chisulryoung Volcanic Formation was preceded by the intrusion of late Cretaceous Nijeonri granodiorite and hornblende granodiorite and a subsequent period of erosion sufficiently prolonged to unroof the granodirite. The Chisulryoung volcanism may, therefore, have been early Tertiary in age.

Most of the tuffs of the Chisulryoung Volcanic Formation represent pyroclastic flow deposits. In general, they increase in thickness towards the SE and the abundance and grain size of lithic clasts, crystals and pumice also increase towards the SE suggesting a single eruptive source in that direction. Individual tuff members may show local, fairly abrupt, thickness variations probably indicative of a topography contro-

Explanation of Fig. 3 (continued).

7. The upper part of the 5th member showing the recrystallized pumice (bar scale: 0.1 mm)
8. Vitroclastic fabric in upper part of the 6th member (bar scale: 0.1mm)
9. Photomicroscope of lower part of 6th member showing the spheulritic rhyolite clast in weakly recrystalized matrix (bar scale: 0.1mm)
10. Photograph of highly flattened pumice lapilli in central aprt in intrusive welded tuff (bar scale: 1cm)
11. Parataxitic texture in intrusive welded tuff with hornblende granodiorite clast (bar scale: 0.1 mm)
12. Eutaxitic texture in intrusive welded tuff (bar scale: 0.1mm)

lled by penecontemporaneous faulting.

Eruption of the first member was followed by a pause in volcanic activity during which conglomerates derived from an uplifted volcanic terrain were deposited as lenses, perhaps representing alluvial fans or broad channels, on the surface of the tuff. The overlying member is locally thinly bedded and may represent partially reworked pyroclastic flow deposits or air-fall tuffs. Thin tuffaceous sediments overlying the second member indicate that volcanic activity was not continuous.

The third to sixth members are all primary pyroclastic flow deposits emplaced rapidly one after the other and displaying characters varying from ash-flows to block and lapilli flows. They vary from densely welded to non-welded and display the typical characteristic of concentration of lithic clasts and crystals at the base of the flow units and pumice towards the top. They are derived from the SE and may well have been erupted from a vent now occupied by the plug of intrusive welded tuff described below.

THE INTRUSIVE WELDED TUFF

A subcircular area of welded tuff crops out east of Bandong(Fig. 1, 4). The outcrop is about 1km in diameter and the tuffs are well exposed over a vertical distance of 30m. The welding fabric of the tuff dips steeply inward from the contact and indicates a nearly circular funnel shaped structure of intrusive welded tuffs. This intrusion is a pipe or plug with sharp, near vertical contacts with the country rock. Common accidental xenoliths in the intrusive tuffs include hornblende granodiorite, rhyolite, and welded ash-flow tuffs closely comparable in mineralogy and texture to the wall rocks. The pipe is intrusive into hornblende granodiorite in the east and into the Sayeonri and Chisulryoung Volcanic Formation in the west.

The pipe has a composite form (Fig. 4) which

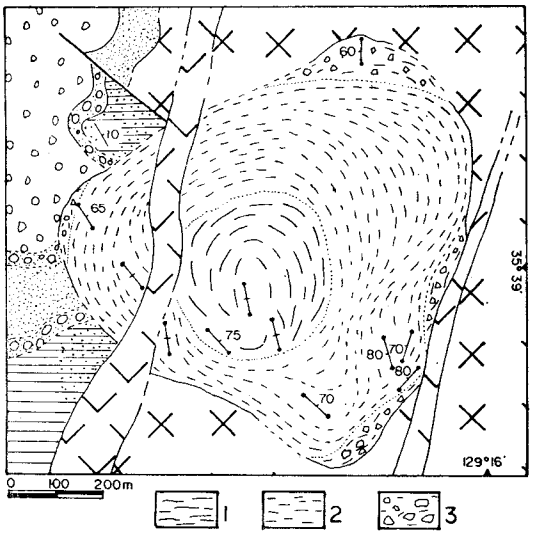

Fig. 4 Geologic map of the Intrusive Welded Tuff and Vicinity. (Legend as in Fig. 1)
1; Central Zone, 2; Inner Zone, 3; Outer Zone

is in part defined by variations in xenolith type and content. In some examples a gradation can be seen from abundant lapilli sized rhyolite xenoliths and rare pumice fragments in the outer zone, to abundant highly flattened pumice fragments and a few locally derived xenoliths in the central part. Phenocrysts of plagioclase, quartz and biotite are also abundant in the central zone.

Hand specimens of the intrusive tuff are seen to contain rare crystals of plagioclase and quartz set in a grey coloured matrix which, where etched by weathering, reveals strong primary foliation. Megascopically the foliation is defined partially by pale brown streaks which appear to be extremely compressed pumice fragments (Fig. 3-10). Some of these streaks are as much as 15cm long although only a few millimetres in width. Megascopically the foliation resembles flow banding in a rhyolite. Near the outer margin the foliation is vertical and parallel to the contact. In the wide, devitrified central zone the foliation dips about 70~80 toward the centre.

Under the microscope, the tuff is seen to

consist of strongly welded volcanic glass with "fluidal" texture(Fig. 3-11, 12) within which are phenocrysts of quartz, plagioclase and, rarely, biotite. Phenocrysts are mainly euhedral plagioclase as much as 1~3mm long. The average size of phenocrysts 1.5mm and though often euhedral, some are broken. Quartz phenocrysts are sometimes present as embayed or hollow crystals. The texture of the groundmass simulates that of a strongly flow banded rhyolite but examination of protected areas, adjacent to phenocrysts, reveals recognizable traces of the former glass shards embedded in matrix. The streaks of collapsed pumice show ragged terminations and internal foliation.

DISCUSSION AND SUMMARY

The virtually identical phenocrysts, groundmass and vpor phase minerals, and the continuity of all lithological unit types in Chisulryoung volcanics are strong evidence that they represent products of the same magma.

The resorption of phenocrysts is generally considered typical of a magma undersaturated with respect to water (Lipman, 1966; Noble, 1970; Robertson and Whyllie, 1971; Steiner and others, 1975). The large amount of resorption of the quartz and plagioclase in Chisulryoung tuff may be an indication of eruption of a water undersaturated magma from a relatively deep chamber. It is considered that in this case, eruption of volumineous ash-flow tuffs may not necessarily be accompanied by caldera collapse. There are no concentric fracture due to collapse related to the Chisulryoung tuffs, or any evidence of caldera or major graben collapse adjacent to the vent region, even though the upper four members of the Chisulryoung Volcanic Formation represent the rapid and virtually continuous eruption of magma.

It is generally accepted that the eutaxitic foliation characteristic of the welded portion of extrusive pyroclastic rocks is the result of load compaction and deformation acting upon hot and plastic glass shards after the pyroclastic flow has come to rest. The foliation thus developed is parallel to base of the sheet and at any point the intensity of welding is dependent upon the viscosity of the glass shards and the load pressure. In the intrusive welded tuff of Weolseong, the foliation is steeply inclined, parallel to the pipe walls, and cannot be formed by gravitational compaction. It is suggested that this foliation may be a flow structure, and thus of primary origin, rather than a post-emplacement feature. The intensity of foliation in the pipe is stronger than in the ash flow tuffs of the nearby Chisulryoung Volcanic Formation.

The concentric internal structure of the intrusive tuff is believed to indicate either varying gas stream velocities (Renolds, 1954), or separate intrusive pulses (Francis, 1959).

Welded tuff dikes with similar features to the Weolseong intrusion are known a few other ignimbrite fields. Some dike-like feeders for ash-flow sheets have been described by Taubeneck (1967). Cook (1968) described two plugs with vitroclastic to flow-banded structure and downward steeping foliation. Koronovsky (1971) described a 40m high vertical dike of flow banded lava gradational upward to pumice, located in the northern Caucasus region, USSR. Several pyroclastic linear and ring dykes, with steep to vertical eutaxitic foliation but lacking a related extrusive phase, have been described by Reynolds (1954), and Brock and Barker (1965).

Evidence has been presented to show that the pyroclastic flows of the Chisulryong Volcanic Formation had their source to the SE of their current outcrop. The welded tuff plug may therefore represent the vent area for one or more of the members of the Chisulryoung Volcanic Formation and in particular the pyroclastic flows

of the upper part of the formation represented by the 3rd to 6th members.

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月城 南部 (鷄述嶺) 地域의 火山岩

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要約：鷄述嶺 地域에 分布하는 火山岩은 Ash flow tuff, intrusive welded tuff 및 Diatreme으로 細分된다. 第三紀 初期에 噴出한 Ash flow tuff는 6個의 層(Member)으로 區分되고, 各層(Member)의 岩相 變化는 岩柱型의 Intrusive welded tuff가 火山 噴出 火口였음을 暗示한다.

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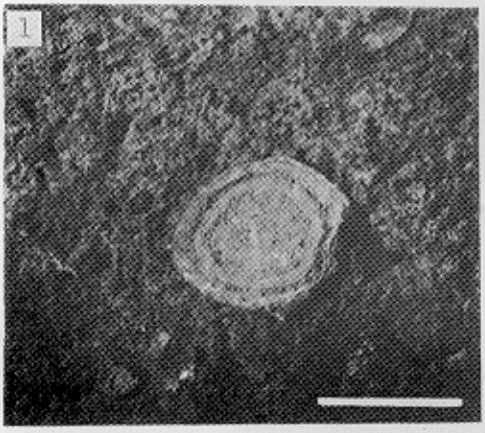
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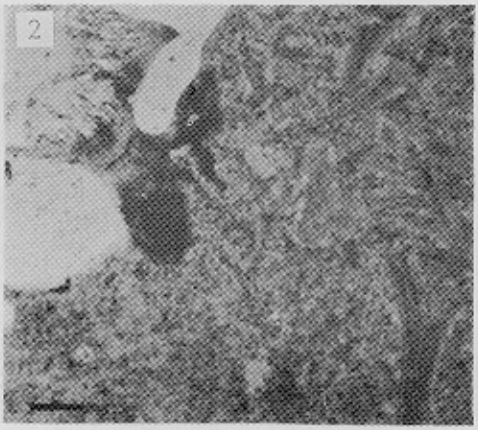
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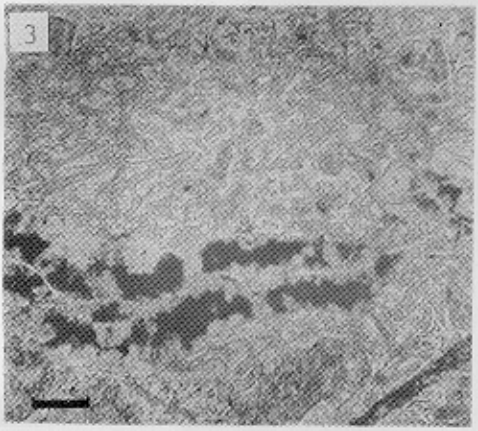
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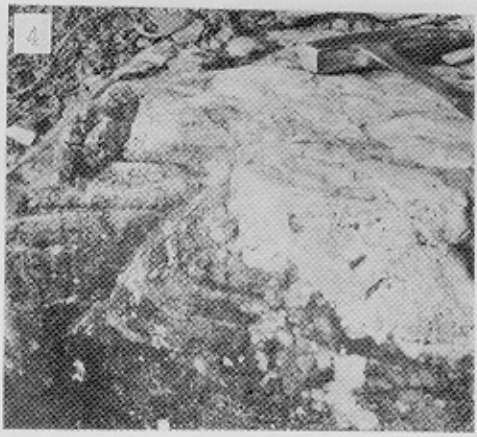
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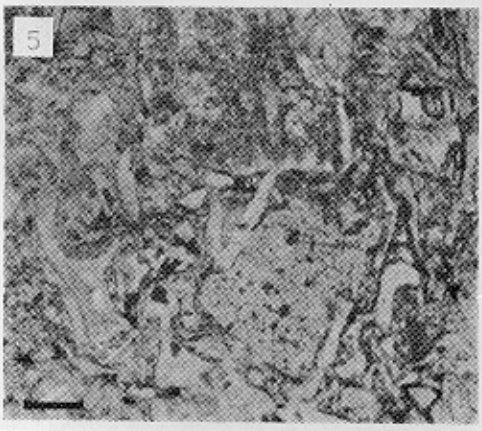
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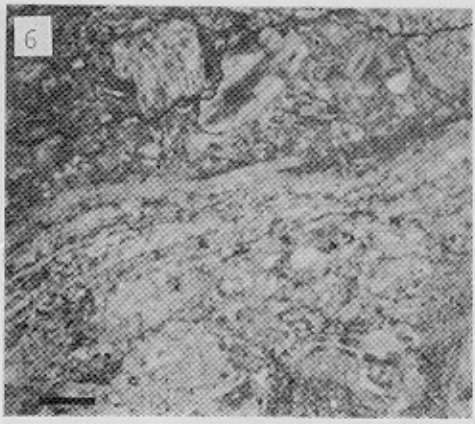
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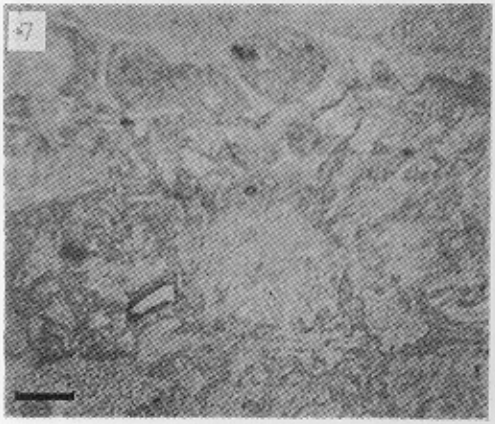
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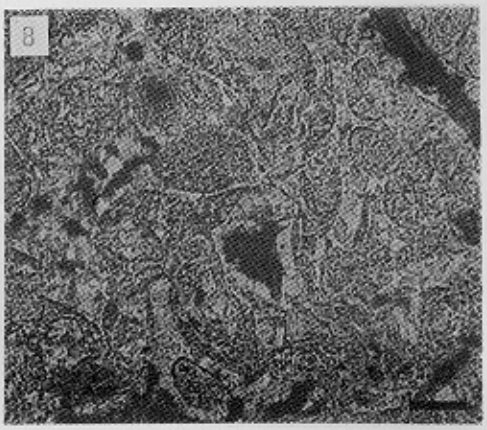
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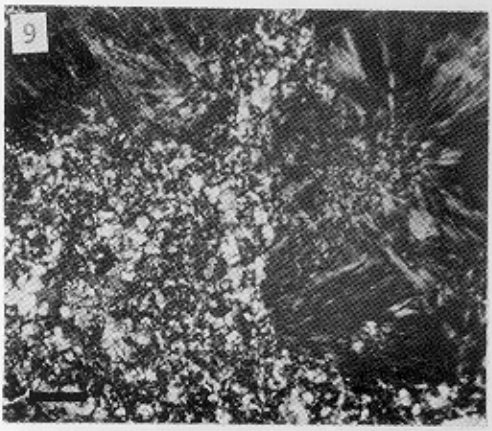
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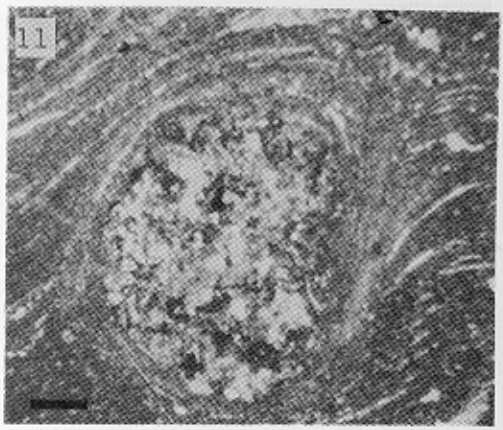
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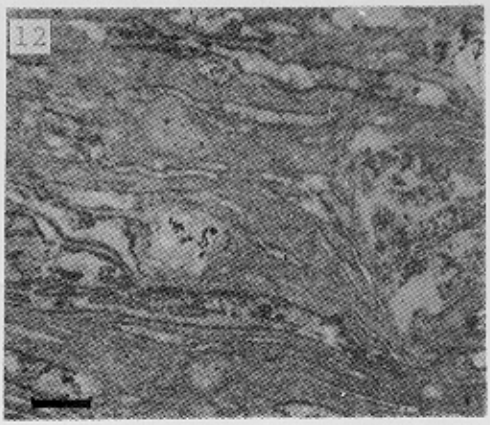
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