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Submicroscopy of Forest Soils(kandiustults) Derived from Granite in Southern Part of Korea[1]

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우리나라 南部地域 花崗巖質 森林土壤의 SEM과 TEM에 의한 觀察[1]

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ABSTRACT

To understand the weathering processes of the soil by submicroscopic method is very important to realize the properties of the soils. In this study soil formation processes show every steps to the changes in chemical and mechanical properties and the submicroscopic characteristics of soil weathering on the profiles of forest soils derived from granite in southern part of Korea.

Fecal pellets(SEM) are given a full detail of the positive activities of the forest soil animals; mainly invertebrates in the O horizon and the E horizon. External shapes of fecal pellets have been divided into five groups : spherical, ellipsoidal, cylindrical, platy and threadlike. But doughnutlike form of fecal pellets is observed in this study.

The soluble and suspended materials in the soils move downwards by percolation from the A horizon to the B or the BC horizons, and result in the illuviation cutans(SEM) on the ped surface of the lower horizon and deposited stack of kaolinite. Illuviated cutans are deposited on the ped surface even in the depth of 312cm in the BC horizon as well as the Bt horizon and comprise of fine silt, coarse clay and fine clay. A lot of halloysites are observed on the cutan surface.

Halloysite formation from feldspars has been well known but a lot of hallyosite formation are observed in this study. The formation were predicted by Jackson(1962), inferred by Wada and Kakuto(1983a, b) and proved evidently by Cho and Mermut(1992a, b). This also suggests that halloysites in the soils derived from granite are formed a lot from ferruginous chlorites.

The release of Fe from the chlorite structure are significant pedogenic processes and newly formed Fe oxides imparted a red color to the soils. The iron oxides particles, which are ejected and recrystalized, aggregate thickly on the edge of the ferruginous chlorites, and this indicates the release of structural Fe from weathered chlorites. Hematites and goethites are frequent in the fine clay in this soils.

Key words : weathered granite, forest soils, submicroscopy, halloysites, iron oxides.

요 약

SEM이나 TEM에 의하여 토양의 풍화과정을 구명하는 것은 토양의 성질을 파악하는데 아주 중요하다. 본 연구에서 우리나라 남부지역 화강암질 삼림토양의 물리 화학적 성질과 초현미경적 특

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성을 파악하여 토양 형성 과정에서 여러 가지 정보를 제공해주고 있다.

O층과 E층에서 삼림 소동물의 적극적인 활동을 증명해주고 있는 동물 배설물인 fecal pellets의 외부형태를 상세히 관찰 할 수 있는데, 외부형태는 spherical, ellipsoidal, cylindrical, platy, threadlike의 5가지로 알려져 있는데(Mermut, 1985) 본 연구에서 doughnutlike 형태가 발견되었다.

토양 微細粒子는 透水에 의하여 상부 A층에서 溶脫되어 B층이나 BC층에서 集積하는데 B층이나 BC층에서 Ped 표면에 集積되어 있는 cutan과 kaolinite가 堆積되어 있는 것을 관찰할 수 있고 cutan은 312cm나 되는 깊은 곳에서도 형성되고 있으며 이 cutan의 표면은 높은 倍率로 관찰하여 보니 fine silt, coarse clay, fine clay로 구성되고 있으며 rod-like halloysite를 관찰할 수 있다.

Fine clay에서 TEM에 의해서 halloysite를 관찰할 수 있는데 halloysite는 長石에서 풍화 생성되는 것으로 널리 알려져 있으며 화강암에서 유래된 ferruginous chlorites에서도 생성되는 사실이 Cho와 Mermut(1992a, b)에 의하여 보고된바 있지만 Jackson(1962)에 의하여 kaolin의 풍화과정이 추론되고 Wada와 Kakuto(1983a, b)에 의하여 우리나라 Alfisols와 Ultisols에서 intergradient vermiculite-kaolin mineral의 생성과정이 추론된 바 있다. 따라서 본 연구에서도 많은 양의 halloysite가 ferruginous chlorite에서 풍화 생성됨을 확인할 수 있었다.

一次鑛物인 chlorites의 構成元素인 Fe가 풍화 과정에서 Iron oxides가 형성되어 토양을 붉은색을 띄게 하여 주는데 Bt층에서 ferruginous chlorites가 exfoliation이 생기며 이 層의 가장자리에 Iron oxides가 結晶集合된 형태로 관찰(SEM)되었으며 fine clay에서 Hematite와 Goethite을 관찰(TEM)할 수 있었다.

INTRODUCTION

Observation of weathering and soil forming processes by submicroscopic method on the every profile of the forest soils is very important to understand the properties of the forest soils. Every soil provides a habitat suitable for animal life. Because of the presence of large quantities of living and dead plant and microbial materials which serve as a continuous food resource, soil animals are generally restricted to the organic or mineral surface horizons. However, animals may also be active at the lower depths. Fecal pellets are excreta that have left animal's intestines as shaped, three-dimensional units. So the essence of fecal pellets is the evidence of animal activities.

Eluviation and illuviation are taking place on the soil profiles and have been recognized as the important pedogenic processes according to weathering progress. Eluviation is undergone the process mainly in the E horizon and illuviation mainly in the B horizon. As a result of weathering processes, so many secondary minerals; kaolinites, halloyosites, iron oxides, illites, vermiculites, gibbsite and sericite etc, are new formed by the alteration of primary minerals of granitic rock. Kaolinites, halloysites and iron oxides among the secondary minerals are mainly observed by the submicroscopy in this study. Weathering patterns of granitic rocks are fairly well described in different bioclimatic regions (Harris and Adams, 1966; Gilkes and Suddhiprakarn, 1979; Melfi et al., 1983). The use of micromorphological and submicroscopical techniques (Eswaren and Bin, 1979; Mermut et al, 1986; Cho et al., 1992a, b) and experimental work in the laboratory(Berner and Holdren, 1979; Holdren and Berner, 1979) have added new dimensions to studies related to weathering. Studied soils derived from granite and occupy about a third of the land area in Korea, 13% in Japan(Soil Technology Society of Japan, 1979) and considerable area in China, especially in Manchulia(Li and Sun, 1990). Most of the soils derived from granitic rocks in the Far East are under forest cover.

This study utilized submicroscopy with the chemical composition and mineralogy of the forest soils(kandiustults) derived from granite in southern part of Korea.

MATERIALS AND METHODS

The study site is located in the Naju city, Chollanamdo, Korea. Vegetation is dominated by red pine trees (*Pinus densiflora*) with understory vegetation of shrubs and grasses. The site is situated on a moderately steep concave slope(16%) and the soils are derived from metamorphosed granite with high amounts of ferrugious chlorite. The soils are dry for 90 or more cumulative days in most years; therefore, the moisture regime can be classified as ustic(Soil Survey Staff, 1990). The soils can be classified as loamy, halloysitic, thermic kandiustults(Soil Survey Staff, 1990).

The soils were described in the field and classified according to Soil Survey Staff (1990). Composited bulk soil samples, collected evenly throughout the entire horizon, were passed through a 2-mm sieve. The particle size analysis was by pipette method after treatment to remove organic matter and ultrasonification(3min, 250w). The CEC and exchangeable cations were determined using $BaCl_2$ triethanolamine at pH8, free Fe and Al by DCB, and organic C by dry combustion techniques.

For submicroscopical studies, a Philips 505 SEM and an EM 400 TEM(both by Philips Corp., Eindhoven, the Netherlands) were utilized. Undisturbed soil aggregates were used in the SEM studies. The samples for TEM, impregnated with Spurr's resin (J.B.E.M. Servies, Dorval, PQ, Canada), were cut into ultrathin slices($\approx$120nm) with a diamond knife and studied at an accelerating voltage of 100kV.

RESULTS AND DISCUSSION

1. Soil characteristics

A short profile description of the soils is given in Table 1. The soils have a very thin($<$5cm) organic layer. The light brown(7.5YR 6/4) to brown (7.5YR 5/4) color of the E horizon makes it distinctly different from the light red(2.5YR 6/8) to red (2.5YR 5/8) color of the very thick($>$2m) Bt horizon. The color of the BC horizon is pink(7.5YR 7/4) to light brown(7.5YR 6/4). The structure in the Bt horizons is moderately well developed and fine subangular blocky peds and BC horizon shows well the distinction of granitic weathering which has weak coarse angular blocky peds with some prismatic or platy peds. The brittle, thick BC horizon(>3m) is underlain by saprolite. Hardness in the Bt horizon is hard in dry and friable in moist inspite of being loose in dry or moist in BC horizon, and the stickiness in the Bt is slightly sticky inspite of being nonsticky in the BC, and plasticity in the both Bt and BC is slightly plastic.

Selected physical and chemical properties of the soils are presented in Table 2. The pH is very strongly to moderately acid and EC values are extremely low. Particle-size distribution is almost identical. Whereas the texture of the E and BC hori-

Table 1. Morphological description of the two soils studied.*

Horizons	Depth (cm)	Color		Texture	Structure	Consistence				Boundary	Special features
		dry	moist			dry	moist	wet (stickiness)	wet (plasticity)		
O	2.5-0										Moder
E	0-63	7.5YR5/4	7.5YR6/4	sl	1m sbk-pl	dsh	mvfr	wss	wps	as	Few roots and including decomposed plant residues
Bt	63-304	2.5YR6/8	2.5YR5/8	scl	2 f sbk	dh	mfr	wss	wps	ai	Clay illuviation
BC	304-629	7.5YR7/4	7.5YR6/4	sl	1 c pr-abk-pl	dl	ml	wso	wps	ai	Easily broken, speckled yellowish white aggregates

*Abbreviations from Soil Survey Staff, 1951, p. 139-140.

Table 2. Selected physical and chemical properties of the soils studied.

Horizons	Depth	pH (paste)	Condu-ctivity	Total sand	Total silt	Total clay	Fine clay	Fine clay/ total clay	Organic C	CEC	Exchangeable cations K	Na	Mg	Ca	DCB-extractable Fe_2O_3	Al_2O_3
	cm		dS m^{-1}	———	%	———			g kg^{-1}	———		$cmol_c$ kg^{-1}	———		—— % ——	
E	0-63	4.78	0.13	68	17	15	5	0.33	2.5	9.81	0.11	0.10	0.04	0.42	1.29	0.26
Bt	63-304	5.15	0.12	48	22	30	10	0.33	1.2	12.66	0.16	0.33	1.07	0.36	5.00	0.53
BC	304-629	5.21	0.11	68	21	11	2	0.18	1.0	11.78	0.32	0.22	4.65	2.05	2.27	-

zon is sandy loam, the texture of the Bt horizon is sandy clay loam. The clay contents in the Bt horizon is almost three times higher than in the BC horizon. The amount of silt remains almost uniform throughtout the profile. Another typical characteristic of the soils is the low fine-clay to total-clay ratio of all the horizons. Organic matter, except in the very thin organic layer, is extremely low, indicating poor nutrient-supplying capacity of the soils. CEC is low but is higher in the Bt horizon than in the

Figure 1. Decomposed plant residues and fecal pellets in the O horizon.
(A) Needle leaf of red pine tree(*Pinus desiflora*) being decomposed; the skeleton of cell wall(a) and fecal pellets on the surface in the cavity of decomposed needle leaf(b).
(B) Doughnutlike(a), cylindrical(b) and ellipsoidal fecal pellets(d) on the outer surface of decomposed needle leaf and stoma of needle leaf(c).
(C) Magnified ellipsoidal fecal pellet.
(D) Magnified cylindrical fecal pellet with fungus hyphae(arrows).

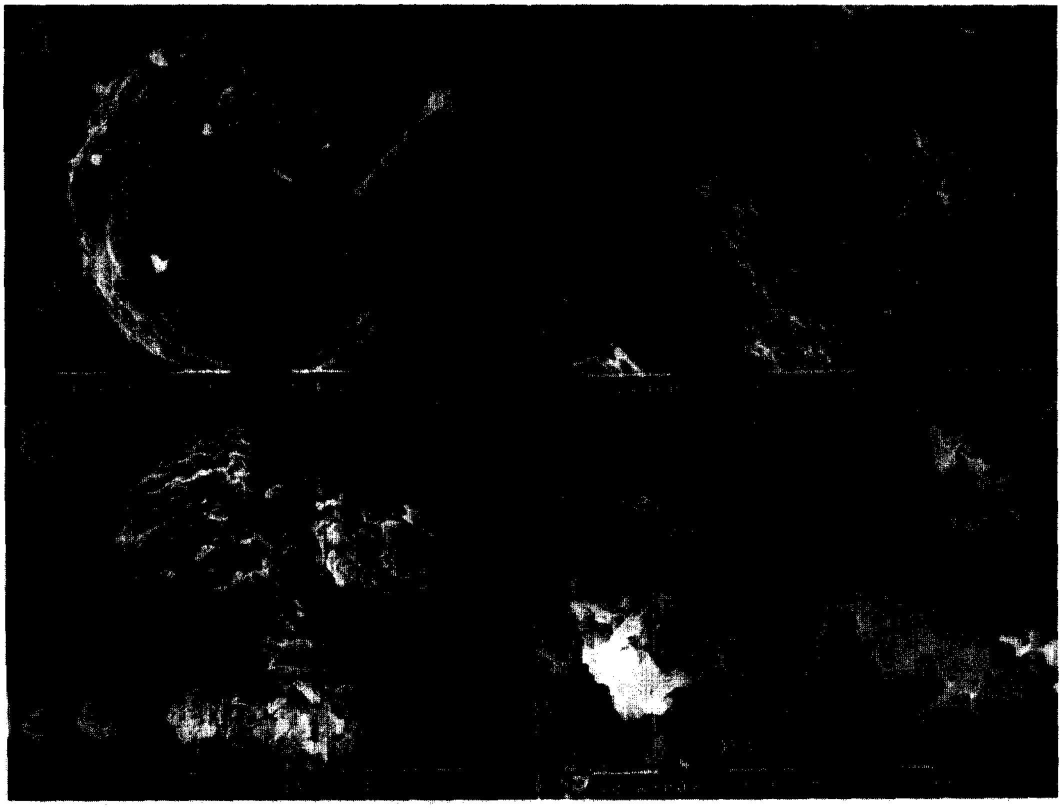

Figure 2. Fecal pellets, and loosened soil aggregates by eluviation in the E horizon.
(A) Spherical fecal pellet.
(B) Stack of cylindrical fecal pellet on the surface of big mineral fragment.
(C) Magnified cylindrical fecal pellets.
(D) Loosened mineral particles by eluviation.

E and BC horizons, due to the high clay contents. The soils are poor in bases(base saturation<50%). Despite the reddish color, the DCB-extractable Fe and Al contents of the whole soils are not high, but higher than soils in temperate regions.

2. Submicroscopy

The surface of the O horizon consists entirely of plant components, little affected by decomposition whereas entirely decomposed organic fragments. The micrographs of the decomposed needle leaves of red pine tree(*Pinus densiflora*) give a full detail of decomposition(Figure 1, A, B). The fungus hyphae spread into the crack of the tissue and on the surface of the needle leaf of red pine tree and the remnants of organic matters.

The micrograph of decomposed needle leaf of red pine shows skeleton of the cell wall(Figure 1, A : a) and the fecal pellets are on the inner space of the decomposed needle leaf(Figure 1, A : b) and on the surface of the needle leaf(Figure 1, B : a, b, d). Fecal pellets are the excreta that have left soil animal's intestines as shaped, three-dimensional units. Animal excrement, togehter with organic residues, is essential in the formation of soil aggregates. Recognizable fecal pellets can be seen in a pedo-tubule, inorganic horizon, or within large intercon-nected pore spaces(Figure 2, A, B, C). It is already known that a major subdivision of fecal pellets can be based on external shape and can be distinguished five groups(Mermut, 1985) : spherical (Figure 2, A), ellipsoidal(Figure 1, A : b, B : d, C) cylindrical (Figure 1, B : b, D, Figure 2, B, C), platy and threadlike. But other form of doughnutlike shape is found in this study(Figure 1, B : a) and more details of this form will be introduced in forth-coming paper. Magnified micrograph(Figure 1, C) of the fecal pellet on the inner space of the decom-posed needle leaf(Figure 1, A;b) give a full detail of the fecal pellet. Fungus hyphae are close to the cylindrical fecal pellet (Figure 1, D). Fecal pellets were found in the depth of 149cm(Cho et al., 1992a) in the Bt horizon, proving the activities of the forest soil animals at the lower depth.

The downward movement of soluble and sus-pended materials in the soils is taken place by percolation, from A horizon to the B or BC horizon, so that transported fine silt, coarse clay and fine clay are deposited on the ped surface of the lower horizon(Dasog et al., 1987). The ground mass on the E horizon is loose as a result of eluviation which is well visualized by submicroscopy of the E horrizon(Figure 2, D). The micrograph(Figure 3, A) shows the stack of kaolinite particles accumu-lated randomly in the Bt horizon(149cm deep). Presence of illuviation cutans in very fine-textured soils is rarely reported. The ped surface in the Bt horizon shows illuviation cutans, comprisied of fine silt, coarse clay and fine clay together with pure clay cutans(argillans) (Figure 3, B, arrows, Figure

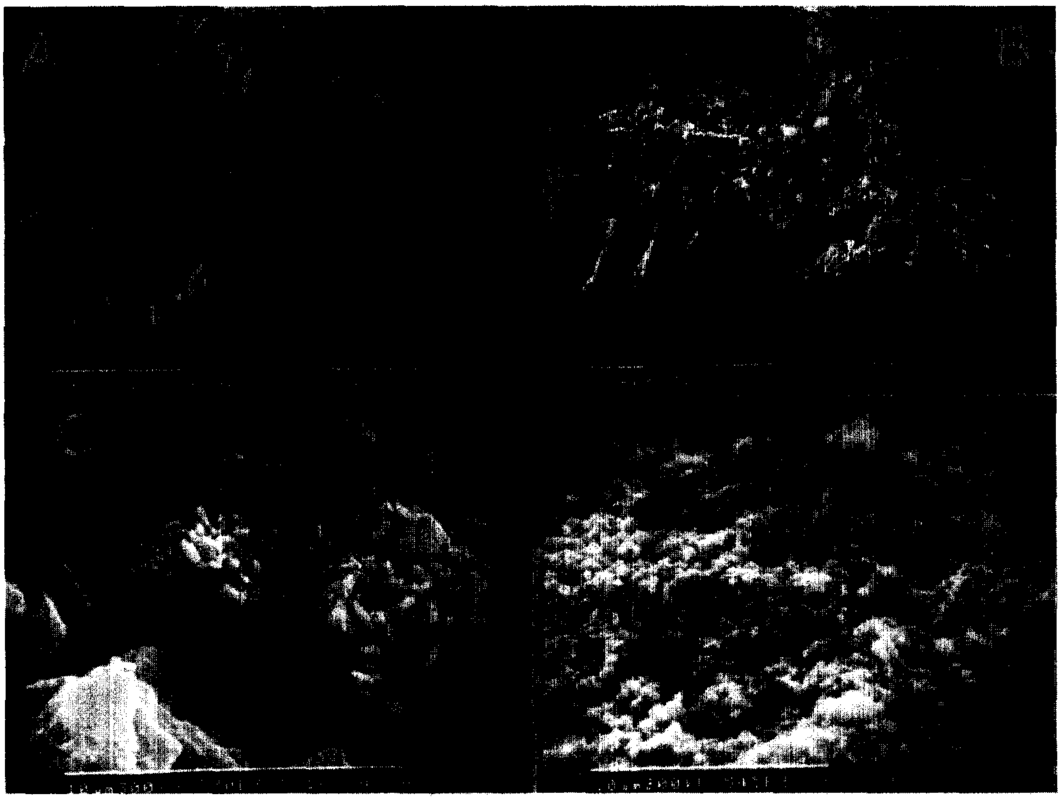

Figure 3. (A) Illuviated kaolinite particles in the Bt horizon.
(B) Illuviation cutan on the ped in the Bt horizon(arrows).
(C) Halloysite formation from ferruginous chlorites in the Bt horizon.
(D) Rodlike ones of halloysite(arrows) and iron oxides on the surface of ferruginous chlorites in the Bt horizon.

4, B, D). Illuviation cutans are deposited on the ped surface even in the depth of 312cm in the BC horizon(Figure 4, B, D) as well as in the Bt horizon. A magnified view of the cutan comprised of coarser particles reveals their lamination and inclusion of silt-size particles in spite of comprising of fine clay particles with relatively strong orientation(Figure 4, B, D). Poor orientation has also been attributed to the presence of fine silt-size mica in cutans and a lot of halloysites are observed on the deposited clay coarting of the cutan surface(Figure 4, D, arrow). The halloysites and iron oxides are observed so frequently that the characteristics of the metamorphosed granite in this study is evidently confirmed. It is well known that halloysite is secondary mineral from feldspars (Walter E. P. 1969). Cho and Mermut(1992a, b) reported that halloysites were formed from weathering of the chlorites in the granite, as well as from feldspars weathering(Cho, 1997). In this study, it is also observed that halloysites are formed from the flakes of ferruginous chlorites(Figure 3, C) and formed on the edge of exfoliated ferruginous chlorites(Figure 4, A, C). Cho and Mermut(1992a, b) found that the soil clays contained an uncommon hydroxy interlayered vermiculite(HIV)-kaolinite intergradient. The clays, occuring in weathered granite soils in the southern part of Korea, contained

Figure 4. (A) Halloysites are forming on the edge of the ferruginous chlorites in the BC horizon.
(B) Illuviated cutan in the BC horizon.
(C) Magnified micrograph of tetragon(□) in the micrograph A shows the forming halloysites(gumlike materials) in the BC horizon.
(D) Magnified view of the cutan surface of the micrograph B comprised of fine silt, coarse clay and fine clay, and rodlike ones are halloysites(arrow) in the BC horizon.

halloysite, kaolinite, hematite, and gibbsite, as well. Jackson(1962) predicted the formation of kaolinite and halloysite from chlorite by the summarization in equation of various weathering reaction and indexes. And Wada and Kakuto(1983a, b) inferred that 14Å mineral was to be an intergradient vermiculite-kaolin mineral and to represent an intermediate phase during the transformation of 2 : 1 to 1 : 1 layer silicates in temperate, red and yellow soils (Korean Alfisols and Ultisols). Kaolinite formation from feldspars, mica and especially biotite is known, but formation from chlorite does not appear to be common. The formation of the intergradient vermiculite-kaolin as described by Wada and Kakuto (1983a, b)has weighty implication in the transformation of 2 : 1 to 1 : 1 minerals during weathering.

Bundles of dehydrated tubular, and typical crumpled lamellar halloysites are very distinct in the Bt and BC horrizons of the soils studied(Cho, 1997)(Figure 3, C, Figure 5, B).

Micrographs(Figure 4, A, C) show the halloysite formation from the flakes of the ferruginous chlorite(gum-like materials with iron oxides formed on the flakes of the weathered chlorite particles). Considering the amounts of extractable Fe by DCB in the Bt and BC horizons, the halloysite appears

Figure 5. (A) Fe oxyhydroxide aggregates at the edge of ferruginous chlorites in the Bt horizon.
(B) Transimission electron micrograph showing the tubular halloysite(a), hematite(b), goethite(C) and chlorite-vermiculite intergrades(d) in the fine clay of the BC horizon.
(C) Lattice-fringe images of 1.4nm intervals of the original chlorite from the granite parent rock(× 1,000,000).
(D) Lattice-fringe images of 0.7nm intervals of the weathered chlorite from the BC horizon(× 800,000).

to contain appreciable amounts of structural Fe. Cho and Mermut(1992b) reported that high CEC of the chlorite flakes from the Bt horizon also confirmed that the majority of the resulting 1 : 1 silicate mineral after chlorite is halloysite rather than kaolinite. CEC of the soils studied show higher in the Bt and BC horizons than in the E horizon (Table 2) and halloysite formation was easilly founded in the Bt and BC horizon(Figure 3, C, Figure 4, A, C). The TEM micrograph of ultramicrotome-sectioned original chlorites from the granite parent rock shows 1.4nm of lattice-fringe images(Figure 5, C) and micrograph of weathered chlorite from the BC horizon shows alteration (0.7nm) to secondary minerals(Figure 5, D). Ahn and Peacor(1985) reported that a chlorite packet was intergrown with layers of mixed-layer illite/smectite and locally 0.7nm layers were intercalated within 1.4nm chlorite from argillaceous sediments (Lee and Peacor, 1985). Cho and Mermut(1992b) reported that the TEM of the ultramicrotomed section of the original chlorites from granite parent rock revealed the configurations involving successive individual clay layers. Lattice-fringe images of chlorite crystallographic planes spaced at 1.4nm intervals were visible on many of the particle sections and the 0.7nm layers were locally intercalated (mixed layering) with 1.4nm chlorite. Cho and Mermut(1992b) confirmed that locallized areas in the chlorites indicated the presence of structural disorders or some alterations already started within the chlorite in the parent rock.

The release of Fe oxyhydroxide from the chlorite structure and formation of hematite and goethite were significant pedogenic processes and these newly formed Fe oxides imparted a red color to the soils. This red color of the soils is significant characteristics in granitic soils in Korea. Cho and Mermut(1992a) reported that the amount of ferruginous chlorite in the weathered granitic soils were unusually high and while some grains still remained partly weathered in the E and BC horizons, no original chlorite could be observed in the Bt horizon. Fe-oxyhydroxides are mainly derived from the ferruginous chlorites in this soils. Iron oxides could be observed with SEM(Figure 5, A) and in the fine clay sample with TEM(Figure 5, B). Iron oxides particles are ejected from the ferruginous chlorites and recrystallized aggregate thickly at the edge of the exfoliated ferruginous chlorite flakes(Figure 5, A) and this indicate the release of structural Fe from weathered chlorites. Hematite and goethite which are ejected and recrystallized are frequent in the fine clay in the Bt horizon and also in the BC horizon of this soils and chlorite-vermiculite intergrades are foggilly observed(Figure 5, B). Cho reported(1997) that synthetic hematites were clearly observed with TEM and supposed to be alteration products on the surface of biotite grain, but iron oxides from biotite are kind of observed in this study.

CONCLUSIONS

The studied soil have a very thin organic layer (<5cm), have thick Bt horizon (<2cm) imparted red or light red color to the soils and have very thick brittle BC horizon (>3cm) imparted pink or light brown color to the soils. The whole profile of the soils shows the well developed aspect of the weathered granitic forest soils in southern part of Korea.

The results studied by submicroscopy are as follows :

1. Three groups in the external shapes of fecal pellets; spherical, ellipsoidal, cylindrical forms, are given a full detail of micrographs and other form of doughnutlike fecal pellet is observed in this study.
2. The eluviation in the E horizon and illuviation in the Bt horizon by the downward movement of soluble and suspended materials are well visualized in this study and result in the illuviation cutans and the stack of kaolinite particles. Illuviation cutans are deposited on the ped surface even in the depth of 312cm in the BC horizon

as well as in the Bt horizon.

3. Bundles of dehydrated tubular and typical crumpled lamellar halloysites are very distinct in the Bt horizon of the soils studied and it was evidently confirmed that these halloysites are mainly formed at the edge of ferruginous chlorites of the granite. This indicates the type of edge weathering of chlorit particles
4. Ejection and recrystallization of iron oxides are observed at the edge of ferruginous chlorite particles, indicating the release of structural Fe from the ferruginous chlorites of the granite. Hematites and goethites are frequently observed in the clays of the soils studied.

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