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Composition and Genesis of Volcanic Ash Soils in Jeju Island. I. Physico-Chemical and Macro-Micromorphological Properties

濟州道 火山灰土壤의 特性 및 生成에 關한 研究. I. 理化學 및 形態學的 特性

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ABSTRACT : The effect of soil forming factors on the pedogenesis of basaltic volcanic ash soils and the influence of allophane material on soil properties have been investigated on 5 chronosequence soils situated from at the near sea coast up to the foot slope of Mt. Halla in Jeju Island. Time seems to be the most important soil forming factor which today differentiates soil of the Island. Songag and Donghong soils developed in lower elevations are older and somewhat less influenced by ash shower. However, soils developed at higher elevations, Pyeongdae and Heugag, are rather younger and strongly influence by the ash. It is also proved that the parent materials are very heterogeneous. They mainly are basaltic with some contamination of acidic volcanic ashes and continental aeolian deposits where a considerable amount of quartz encountered in most soils studied. Many physico-chemical properties of soil, such NaF pH, phosphate sorption power, Δ pH and extractable acidity are parameters to differentiate andepts and non-andeptic soils.

要約 : 濟州道 玄武岩 火山灰에서 由來된 火山灰土壤의 特性 및 土壤生成因子을 究明하기 위하여 漢拏山기슭에서 海岸까지 分布된 5種 Chronosequence 土壤에 대한 研究結果 時間이 土壤生成에 있어 크게 影響한 因子임이 밝혀졌다.

海岸가까이에 發達된 松岳 및 東烘統은 土壤生成年代가 오래되어 粘土의 集積層이 있었고 간혹 火山灰의 影響을 받았으나 非火山灰土壤으로 確認되었고 산기슭에 發達된 坪垈 및 黑岳統은 生成年代가 오래지 않았고 주로 火山灰에서 基因된 母材에서 發達되었으나 大陸에서 飛來된 石英을 含有하는 等 매우 不均一한 火山灰土壤이었다.

土壤特性 특히 pH(NaF), ΔpH, 燐酸吸收能, 置換酸度에 의하여 本 研究土壤을 火山灰土壤과 非火山灰土壤으로 區分할 수 있었다.

INTRODUCTION

Jeju Island is situated between 33° 10′ and 33° 35′ north latitude and between 126° 10′ and 126° 58′ east longitude. The relief of the Island is dominated by the Mt. Halla (1950m) which is located in the middle of Island. Mt. Halla is a shield volcano with the largest crater lake of diameter 500m. The Island is characterized by a system of successive lava plains. She is dominantly covered by basalts with some trachytes and trachy-andesites. Volcanism of Island has been active on a basaltic basement since late Tertiary up to the recent time (Kim, 1963). The volcanic ash totals to 90% of surface and thus the parent material as volcanic ash is an important pedogenic factor on the Island soils. Most volcanic ash is derived from Mt. Halla, the principal centre of ash showers. In addition to the big crater of Mt. Halla, more than 360 cinder cones are distributed over the Island, so that the ash of each shower is mixed or interstratified, what make it rather difficult to identify the origin of each ash deposit. Moreover, the Island has been gradually formed by the uplifting by five main eruptions and 79 lava flows (Won, 1976). In addition, the native grasses are main in vegetation. The Island has a Cfa (Köppen) and B3rB′2B′4 (Thornthwaite, 1948) climatic classification. The mean annual precipitation varies from 1,400 to 1,800mm. The rainfall increases from June to August, then decreases to a minimum between December and February. Over 50% of the precipitation falls from July to September. These unique vegetation and climate conditions did also influence on soil formation. Therefore, the soils developed on Island have a wide variation. The purpose of this study is to characterize the soils influenced upon ash with specific reference to the effect of allophanic material on soil properties and genesis.

MATERIALS AND METHODS

The five representative soils were selected on basis of detailed soil survey map (IAS, 1976). Songag series (Typic Hapludalf) comprises brown to yellowish red soils (5YR) which are probably developed on the mixture of old ash and alluvium near the coast; Donghong series (Ultic Hapludalf) brown to dark brown soils (10YR) derived from the mixture of alluvium and aeolian or old ash deposits. Ora series (Typic Dystrandept) very dark brown soils developed on ash with some loess. Pyeongdae series (Typic Dystrandept) black soils developed on ash and Heugag series (Typic Hydrandept) brown to dark brown soils developed on the volcanic ash over cinder cone (Scoria). These are situated near each other, forming a chronosequence. Other information of these soils is given elsewhere (Shin, 1978). Field description was made following the soil survey manual (Soil Survey Staff, 1951) and the Guidelines for soil description of FAO; the soil colour was described according to the Munsel colour chart (Munsel colour Co., 1954). Micromorphological study was conducted on the thin sections of dry and moist soils after impregnation with polystyrene (Stoops, 1974). Moist soil sections were made on natural moist samples in order to determine the microstructure changes after drying; for this the samples were put into acetone for about 2 weeks (the acetone was changed every 24 hours), thus the water was gradually replaced by acetone. Major micromorphological features are described according to Brewer(1968). Soil samples were also collected by horizon and air-dried in the shade and passed through a 2mm sieve after gentle crushing with a wooden rolling pin. The particle size distribution of the fraction below 2mm was determined by the pipette method. All samples were pretreated with 30% H_2O_2 and 5% sodium hexameta-phosphate was used as a dispersing agent. The moisture retention at 1/3 and 1/10 bars was determined using a pressure-plate apparatus and at 15 bars it was determined a pressure-membrance apparatus. The bulk density was calculated by dividing the weight of oven-dry cores by their volume. The soil pH was determined in a 1 : 1 soil water and 1N KCl ratio of 1 : 1.

Sodium fluoride pH was determined by weighing 1g of soil adding 50ml 1N NaF solution, and reading the pH at 2 min. (Fields and Perrott, 1966). The organic carbon was determined on 0.5g sample by Tiurin's method using chromic acid. The CEC of a 1N NH_4OAC buffered solution (pH 7) and a 1N NH_4Cl unbuffered solution (pH±4.5) was determined. CEC (sum) was calculated by the summation of the extractable bases (NH_4OAC, pH 7) and the extractable acidity (BaCl-TEA) at pH 8.2. Exchangeable bases were determined with an atomic absorption spectrophotometer by using the neutral 1N NH_4OAC leachate. P_2O_5 sorption was determined on a 50g soil sample by adding 100ml of a 2.5% ammonium phosphate solution at pH 7.0 (Shin, 1978).

RESULTS AND DISCUSSION

The main field characteristic is soil colour shown in Table 1. The colour is generally influenced by the amount of organic matter and free iron oxides present (Table 2). Songag series

Table 1. Macro-micromorphological features of the representative profiles.

Soil name	Horizon	Depth (cm)	Color	Texture	Structure	Micro-structure	Plasmic fabric
Songag	A1	0~ 20	5YR 3/3	SiL	M,fm,G	VP	In
	B21t	20~ 40	5YR 4/5	SiL	W,Mm,SAB	P	In
	B22t	40~ 70	5YR 5/6	SiL	W,Mm,SAB	P	Ma
	B23t	70~120	5YR 5/6	SiL	W,Mm,SAB	P	Ma
Donghong	A1	0~ 20	10YR 4/4	SiL	W,fm,g	P	In
	B1t	20~ 46	10YR 5/6	SiCL	W,fm,SAB	P	In
	B21t	46~ 70	10YR 5/6	SiCL	W,fm,SAB	IJ	Ma
	B22t	70~ 90	10YR 5/6	SiCL	W,fm,SAB	IJ	Ma
	B23t	90~120+	10YR 5/6	SiCL	W,c,B	IJ	Ma
Ora	A1	0~ 18	10YR 3/3	SiL	M,fm,G	C	Is
	A3	18~ 35	10YR 3/3	SiL	W,fm,G	C	Is
	B1	35~ 70	10YR 3/4	SiL	W,fm,SAB	VP	Sil
	B2	70~ 90	10YR 3/3	SiL	W,c,SAB	VP	Sil
	B3	90~120	10YR 3/4	SiL	W,c,SAB	VP	Sil
Pyeongdae	A11	0~ 24	10YR 2/2	SiL	MS,fm,G	SC	Is
	A12	24~ 37	10YR 2/1	SiL	WM,Mm,G	SC	Is
	B1	37~ 65	10YR 3/1	SiL	W,c,B	SC	Is
	B2	65~ 90	10YR 4/1	SiL	W,c,B	SC	Is
	B3	90~120	10YR 4/1	SiL	W,c,B	SC	Is
Heugag	A1	0~ 20	10YR 3/2	SiL	M,f,G	VP	Is
	B1	20~ 35	10YR 4/2	SiL	W,c,B	VP	Is
	B2	35~ 70	10YR 4/3	SiL	W,c,B	VP	Sil
	B3	70~ 90	7.5YR 5/6	SiL	Ma	P	Sil
	C	90~120	7.5YR 5/8	SiL	Ma	P	Sil

Texture code: SiL-silt loam, SiCL-silty clay loam
Structure code: W-weak, M-moderate, WM-weak to moderate MS-moderate to strong, f-fine, Mm-medium, c-coarse, fm-fine to medium, G-granular, SAB-subangular blocky, B-blocky, Ma-massive
Micro-structure code: VP-very porous, P-porous, IJ-irregular jointed, C-crumbly, SC-spongy to crumbly
Plasmic fabric code: In-insepic, Ma-masepic, Is-isotic Sil-silasepic

Table 2. Some physico-chemical properties of soils studied.

Soil name	Horizon	Sand (%)	Silt (%)	Clay (%)	B.D. (g/cc)	15bar H_2O (%)	pH			O.C (%)	Free (%)		P_2O_5 Sorption (mg/100g)	Extractable bases (me/100g)			CEC (me/100g)
							H_2O (1 : 1)	KCl (1 : 1)	NaF (1 : 50)		Fe_2O_3	Al_2O_3		Ca	Mg	K	
Songag	A1	29.5	44.7	25.8	1.05	24.6	5.6	4.5	9.3	2.97	5.34	1.03	944	3.5	4.8	0.5	28.8
	B21t	35.6	36.4	28.0	1.16	20.6	6.7	5.2	9.6	0.46	4.91	0.69	828	4.6	7.3	0.1	25.2
	B22t	36.6	37.1	26.3	1.27	20.9	6.7	5.4	9.6	0.42	5.10	0.50	736	4.0	7.5	0.1	23.9
	B23t	29.2	40.3	30.5	1.36	21.0	6.7	5.4	9.6	0.28	5.05	0.50	852	4.7	9.2	0.3	23.7
Donghong	A1	5.0	70.4	24.6	1.15	12.6	5.3	4.2	9.6	1.85	2.24	1.00	1,220	2.9	0.7	0.1	17.1
	B1t	3.9	61.2	34.9	1.36	16.2	5.0	4.2	9.8	0.66	2.08	0.99	598	2.8	0.7	0.1	16.6
	B21t	5.1	64.3	30.6	1.33	16.0	5.3	4.1	9.3	0.39	2.24	0.82	644	2.5	1.8	0.1	16.4
	B22t	3.5	65.5	31.0	1.47	16.6	5.3	4.1	9.0	0.37	2.02	0.33	644	3.4	2.8	0.1	17.3
	B23t	2.7	62.4	34.9	1.58	16.9	5.6	4.2	8.3	0.24	1.88	0.49	714	4.4	4.3	0.2	17.2
Ora	A1	6.6	72.3	21.1	0.85	29.4	5.1	4.5	11.5	3.51	3.54	4.34	2,048	0.2	0.1	0.1	35.6
	A3	7.0	73.6	19.4	0.80	22.2	5.3	4.6	11.5	2.85	3.35	4.00	2,024	0.4	0.2	0.1	35.8
	B1	8.9	72.9	18.2	0.96	21.0	5.3	4.7	11.6	3.02	4.02	4.32	1,932	0.3	0.2	0.1	35.6
	B2	14.4	65.8	19.8	0.90	22.0	5.4	4.6	11.4	2.46	3.85	3.69	1,864	0.6	0.5	0.1	37.5
	B3	16.2	59.2	24.6	1.05	28.6	5.3	4.5	11.5	2.76	4.09	4.16	1,956	0.6	0.3	0.1	26.5
Pyeongdae	A11	30.4	59.5	10.1	0.54	36.7	5.0	4.8	11.9	7.56	3.82	—	2,300	0.5	0.4	0.2	63.0
	A12	22.3	67.7	10.0	0.49	40.0	5.3	4.8	12.0	8.28	4.52	—	2,576	0.5	0.4	0.1	63.7
	B1	25.6	65.7	8.7	0.48	46.4	5.3	4.8	12.0	6.72	4.38	—	2,530	0.4	0.3	0.1	60.2
	B2	4.3	84.6	11.1	0.60	43.7	5.4	4.9	12.0	5.28	4.20	—	2,408	0.4	0.4	0.1	54.0
	B3	11.5	79.8	8.7	0.65	51.8	5.4	4.9	12.0	6.60	3.75	—	2,554	0.4	0.4	0.1	52.9
Heugag	A1	11.8	71.0	17.2	0.76	30.6	4.9	4.7	12.0	6.96	5.70	—	2,508	0.3	0.3	0.2	59.6
	B1	13.6	69.2	17.2	0.90	27.8	4.9	4.7	11.4	2.76	7.81	2.50	2,323	0.2	0.2	0.1	33.0
	B2	24.4	60.2	15.4	0.86	28.5	4.9	4.7	11.3	1.86	6.39	2.00	2,140	0.2	0.2	0.1	29.1
	B3	15.2	63.5	21.3	0.80	31.2	5.0	4.8	11.3	1.16	6.21	2.00	1,864	0.1	0.3	0.1	30.2
	C	21.6	58.7	19.7	0.82	34.4	5.0	5.1	11.4	1.53	5.78	2.10	2,508	0.1	0.1	0.2	32.0

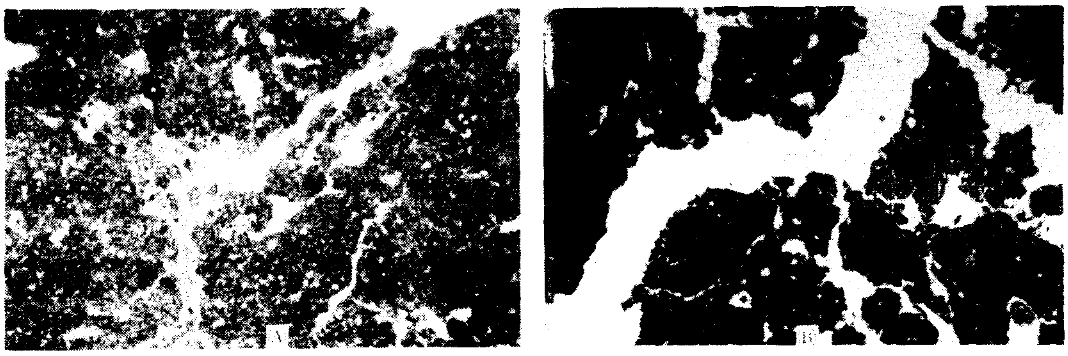

Fig. 1. Comparison between microstructures observed in thin sections from (A) sample impregnated after replacement of water by acetone and (B) air-dried sample. Plain light, 100X.

is developed on the near coast and has a high amount of free iron oxides representing yellowish red colour (5YR). Donghong series is situated at same topography but has finer texture and lighter colour (10YR 4/4 to 5/6). They have an argillic horizon in which layer lattice silicate clays have accumulated by illuviation. It has a strongly developed ferriargillan indicating that it might be older. Ora series becomes darker due to the increased organic matter. Pyeongdae series is black (10YR 2/1) throughout the profile and Heugag series belongs to brown to dark brown colour (10YR 4/3). The colour of soils is directly related with quantity of organic matter as well as free iron content. Free iron oxides do not influence much the colour of the black soils. Their effect may be reduced by the effective melanization of the organic matter (Wright, 1964). It is assumed that the recent ash deposits give rise to a darker colour whereas the colour becomes redder in hue as weathering proceeds and thus brown to yellowish red soil might be older volcanic ash soils than those of black ones. It is nothing in special differences in macrostructure among the soils. The surface horizons have usually a moderately to strongly developed granular.

A relatively high amount of organic matter which is complexed Al and Fe contributes greatly to the formation of this structure. Subsurface horizons have in general different types of blocky. Songag, Donghong and Ora have weakly to moderately developed subangular but Pyeongdae and Heugag have coarse blocky. Pyeongdae and Heugag have a well developed spongy to crumbly microstructure (Beckmann and Geyger, 1967). They were more pronounced after drying. The small individual aggregates were sticking together giving rise to a clustering effect (Kawai, 1969) and a congelic special related distribution pattern (Eswaran and Baño, 1976). This particular pattern of aggregates is supposed to be due to the presence of allophane. After drying the crumbly and spongy microstructure were more pronounced and consisted of discrete rounded aggregates (Fig. 1). Songag

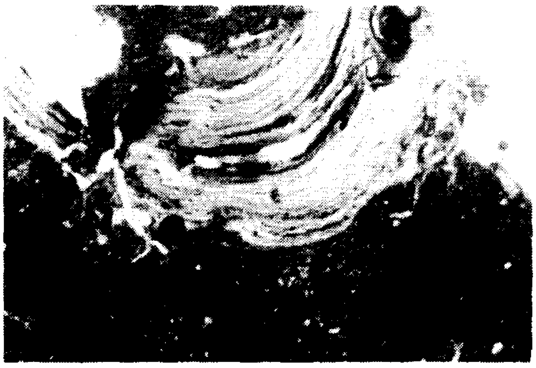

Fig. 2. Strongly developed ferriargillan, showing a papulic aspect. 80X.

and Donghong have a porous or fragmented microstructure with less stable aggregates. There are practically no differences between the wet and air-dried samples. However, they have strongly developed illuviation ferriargillans occurring mostly in channels. Some completely fill channels and voids and show a papulic feature (Fig. 2).

The particle size analysis is uncertain for the ash-derived soils. Table 3 shows the amount of clay determined by the several methods, such as the pipette (sodium hexameta-phosphate), successive sedimentation and calculated methods (2.5×15 bar H_2O content). This clearly suggests that the dispersion of clay is very variable depending on the analytical methods. The reliable values are obtained by the successive sedimentation. The value by pipette method is too low and clay content by calculated one is usually high even over 100%, in Pyeongdae. It is shown that the dispersion of the clay by the normal dispersing method is absolutely incomplete in Pyeongdae and Heugag. The calculated clay content is overestimated in those soils and it is strongly influenced by the amount of amorphous alumino-silicates. An acceptable clay content in the ash-derived soils can be obtained by the successive sedimentation. The silt content frequently show high values in samples with a low clay content. In this case, it is very probable that the silt is composed of clay aggregates (Guedez and Langohr, 1978). The increase of clay content by the successive sedimentation is mainly derived from pseudo-silt particles (clay papules). The degree of dispersion with sodium hexameta-phosphate is closely related to that of soil colour. Songag and Donghong are generally well dispersed, however, Pyeongdae and Heugag are poorly dispersed indicating that they contain a most dominant allophane. Ora series is intermediate.

Table 3. Clay content(%) by different methods.

Soil name	Horizon	Pipette	S.S.*	Calc.clay**
Songag	A1	25.8	40.2	61.5
	B21t	28.0	33.4	51.5
	B22t	26.3	32.2	52.3
	B23t	30.5	30.9	52.5
Donghong	A1	24.6	34.0	31.5
	B1t	34.9	38.0	40.5
	B21t	30.6	42.8	40.0
	B22t	31.0	41.2	41.5
	B23t	34.9	40.4	42.5
Ora	A1	21.1	45.3	73.5
	A3	19.4	46.0	55.5
	B1	18.2	43.0	52.5
	B2	19.8	38.0	55.0
	B3	24.6	46.7	71.5
Pyeongdae	A11	10.1	63.4	91.8
	A12	10.0	62.8	100.0
	B1	8.7	62.0	116.0
	B2	11.1	61.5	109.3
	B3	8.7	57.2	129.5
Heugag	A1	17.2	65.1	76.5
	B1	17.2	58.4	69.5
	B2	15.4	44.0	71.3
	B3	21.3	38.5	78.0
	C	19.9	42.7	86.0

S.S* -Successive sedimentation
Calc. clay**-Calculated clay (2.5×15 bar water)

The amorphous alumino-silicates contain very high amounts of water. This high water holding capacity is also partly associated with organic matter which is generally high in allophanic soils. However, this characteristic might be used to differentiate the studied soils. The ratio of H_2O held at 15 bar to clay content (pipette) is generally high in Pyeongdae and followed by Heugag. Fig. 3 shows a relation between clay content and water held at 15 bar H_2O. Soils which have the value for pH (NaF) higher than 9.4 show a negative curvilinear correlation between clay (%) and 15 bar H_2O. This means that a soil containing high amount of allop-

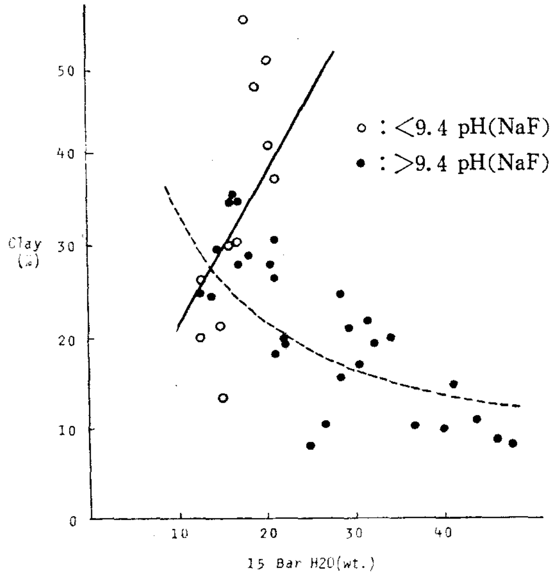

Fig. 3. Relationship between clay content and 15 bar H_2O.

hane has a low content of dispersed clay although the water retention is increased due to the presence of organic matter or allophane.

The pH (H_2O) is generally low in Pyeongdae and Heugag compared to the others. The value of pH (KCl-H_2O) is less than 1unit in soils of Pyeongdae, Heugag and Ora, but higher than 1 unit for the others. This pH (KCl-H_2O) is closer to positive values in Heugag, suggesting that this soil contains a large amount of amorphous constituent (Mekaru and Uehara, 1972). The value of pH (NaF) is generally high, indicating that many of them have been strongly influenced by ash to some extent. The pH (NaF) is one of most useful characteristics to classify the studied soils. Songag and Dongong are generally lower compared to the others. They are lower than 9.4 (NaF) except for some horizons which are still influenced by amorphous alumino-silicates. However, the others are higher than 9.4 indicating that the soils contain a considerable amount of allophone (Furkert and Fieldes, 1968). Another distinguishable characteristic is P_2O_5 sorption power. It is generally accepted that P_2O_5 sorption is higher than 1,500mg/100g of soil in allophane soils (Wada and Harward, 1974). Pyeongdae and Heugag have higher power than 2,000mg/100g soil in P_2O_5 sorption. This level is quite reasonable in differentiating andepts and non-andeptic soils. The high amount of organic matter, especially in subsurface horizons in Pyeongdae is the unique diagnostic characteristic of ash soils. The organic matter content is more or less constant with depth, even for more than 1 m, and this may indicate that the thick organic layer may be gradually formed by successive ash deposits. This is confirmed by differences in mineralogy. Exchangeable Ca and Mg are high in Songag and Donghong which are located at the lower elevations. Pyeongdae and Heugag have very low Ca and Mg. This variation may be partly due to marine or different ash influences. The exchangeable bases are well correlated with the base saturation in soils of Pyeongdae and Heugag suggesting that many exchange sites are occupied by hydrogen and aluminum. CEC (NH_4 OAC, pH 7) is well associated with the amount of amorphous constituents and organic matter content. It is high in Pyeongdae and Heugag and mostly derived from pH dependent charge.

In conclusion, Songag has weakly developed red colour Bt horizons which are still influenced by amorphous constituents. They are well reflected on various soil properties such as pH (NaF), 15 bar H_2O and CEC. The high exchangeable Mg is the most striking feature and it is increased with depth suggesting strong marine influences. Donghong has strongly developed brown Bt horizons with less or no allophane. It has high exchangeable Ca and Mg; especially Mg content is markedly increased with depth indicating some extent of sediment origin. Ora has a transitional characteristic between Donghong and Pyeongdae, however, more closed to Pyeongdae which has the most striking features of volcanic ash soils. Pyeongdae and Heugag have a weakly developed cambic horizon which is originated from rather recent ash. However, exchangeable bases and base saturation of them were extremely low, not exceed more than 1 me/100g of soil. The extremely low bases are reflecting the intensive leaching which take place in highly leaching condition.

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