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# Composition and Genesis of Volcanic Ash Soils in Jeju Island. II. Mineralogy of Sand, Silt and Clay Fractions

## 濟州道 火山灰土壤의 特性 및 生成에 關한 硏究. Ⅱ. 砂, 微砂, 粘土의 鑛物學的 特性

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**ABSTRACT:** Mineralogy of sand, silt and clay fractions from the five chronosequence soils of Jeju Island is studied with the X-ray, TEM and SEM techniques. Soils of Songag and Donghong situated at lower elevations are generally developed on relatively old ash or alluvial deposits and contain mainly ferromagnesian minerals and feldspars, with some quartz, mica and volcanic glass. Crystalline minerals are dominant in the clay fraction; halloysite and vermiculite are abundant but small amounts of allophane are present. Clay migration results in well developed ferriargillan. Soils of Pyeongdae and Heugag located at higher elevations are developed on relatively young volcanic ash with some contamination of continental aeolian dust probably containing quartz which may be come from acid ash shower. The absence of clay illuivation is due to the dominance of allophane. This clay mineral is associated with some gibbsite, imogolite and halloysite.

**要約**：濟州道 火山灰를 母材로 發達된 5種 Chronosequence 土壤의 모래, 微砂, 粘土에 대한 鑛物學的 特性을 分析한 結果는 다음과 같다.

海岸에 隣接한 松岳과 東烘統은 相對的으로 古火山灰와 堆積層에서 發達된 土壤으로 1次鑛物은 含鐵, 苦土鑛物과 長石類가 主鑛物이었고 石英, 雲母 및 火山 glass가 少量 含有되었다.

粘土鑛物은 Halloysite와 Vermiculite가 主鑛物이었고, Allophane이 少量 包含되어 있었다. 粘土의 集積現象이 顯著하여 生成年代가 오래된 土壤에 屬하였다.

한편 漢拏山기슭에 分布한 坪垈 및 黑岳土壤은 近世火山灰層에서 發達되었으며 若干含有된 石英은 大陸風砂 또는 酸性火山灰에 基因된 것으로 判斷되었고 粘土鑛物은 Allophane이 主鑛物이었으며 若干의 Gibbsite, Imogolite와 Halloysite가 含有되어 土壤의 生成年代가 오래되지 않았음을 確認하였다.

## INTRODUCTION

The primary minerals of volcanic ash soils derived from basalic materials in Jeju Island vary according to the nature of parent rocks and the different mineralogy from surrounded rocks is often encountered. This is a reason why the soils from andesitic origin can contain quartz(Mizota and Aomine, 1975). The weathering of the primary minerals (sand fraction) proceeds differentially. On weathering volcanic glass firstly disappears, followed by ferromagnesian minerals and plagioclase feldspar (Eswaran, 1972). Aomine and Wada(1962) reported that volcanic glass and plagioclase are the most easily weatherable minerals. The presence of a considerable amount of quartz encountered in most soils studied, and the origin of quartz is a knotty subject for the basaltic origin. The objective of this study is to evaluate minerals present and their genesis in five chronosequence soils.

## MATERIALS AND METHODS

The general information on the soil samples is given elsewhere (Shin, 1978). The free iron of sand fraction (50~500$\mu$m) was removed with 1N-citric acid under ultrasonic vibration; heavy and light minerals were mounted on petrographic slides for counting. The light mineral sections were stained according to the method of Bailey and Stevens (1960) for differentiating quartz, K-feldspar and plagioclase. Volcanic glass and phytolites were counted as percentage of the total of light minerals. The identification of heavy and light minerals is based on the data present by Kerr(1959). Samples of clay and silt were separated by successive decantation. First, the organic matter of the fraction below 2 mm was removed with a dilute hydrogen peroxide. The organic free samples of Songag and Donghong were then dispersed with a 2% solution of $Na_2CO_3$ at pH 9.0. Since Ora, Pyeongdae and Heugag did not disperse well with the $Na_2CO_3$ solution, a 2% solution of HCl was used. X-ray diffraction (a Philips X-ray apparatus with a Co $K_\alpha$ radiation) was used to identify the clay minerals. 1N HCl treatment was introduced to differentiate kaolinite from chlorite (De Coninck, 1975). Differential thermal analysis (DTA) was carried out with a Dupont 900 thermal analyser. Thermo-gravimetric analysis (TGA) was performed with a Dupont 950 thermogravimetric analyser. Observation was made with the transmission electron microscope (TEM) on untreated clay particles. A study of scanning electron microscope (SEM) was made in order to examine the external of minerals and soil material on the undisturbed samples.

## RESULTS AND DISCUSSION

Mineralogy of sand fraction (50~500$\mu$m) is shown in Table 1. In all the soil series, the heavy mineral association is characterized by a dominance of olivine and high amount of ferromagnesian minerals (Augite, Basaltic Hornblende, Hypersthene) indicating that the parent material is derived from basaltic materials. However, the presence of quartz in the light fraction brings a serious question forward concerning this supposed basaltic origin. It must be noticed that the contribution of the successive ash showers can be different composition. An aeolian origin can be considered to explain the presence of quartz. Coarse silt-sized aeolian quartz may have been deposited during the Quaternary in the area under the influence of the periglacial climate (Syers *et al.*, 1969). Another possible source of quartz is sedimentary, related to sea fluctuation and uplift. This is confirmed by the southern sea cliff and the presence of rounded gravels at high elevations in the northern part (Won, 1976). The occurrence of cristobalite also indirectly suggests the presence of quartz. The occurrence of biotite and muscovite is another characteristic for all the soil groups. The presence of biotite is acceptable for acid to neutral volcanic ash, however, muscovite is also questionable for volcanic rocks. X-ray diffractograms of the silt fraction are generally dominated by quartz peaks (Fig. 1). Quartz is abundant or common in the surface of all the pedons and absent or poorly represented in some subsurface horizons (Fig. 2). These quartz deficient horizons are at least different from the overlying parent materials.

**Table 1.** Mineralogical composition of sand fraction (50~500$\mu$m).

| Minerals \ Soil name / Horizon | Songag | | | Donghong | | | Ora | | | Pyeongdae | | | Heugag | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A1 | B22t | B23t | A1 | B21t | B23t | A1 | B1 | B3 | A11 | A12 | B3 | A1 | B2 | C |
| Heavy minerals (weight %) | 14 | 19 | 26 | 17 | 14 | 15 | 10 | 18 | 13 | 18 | 20 | 19 | 16 | 35 | 20 |
| Olivine | 59 | 59 | 51 | 40 | 62 | 43 | 2 | 7 | 10 | 85 | 77 | 4 | 87 | 80 | 45 |
| Augite | 29 | 32 | 25 | 19 | 15 | 30 | 4 | — | 4 | — | — | 27 | — | — | 40 |
| Hypersthene | 3 | 8 | 5 | 3 | 2 | 10 | — | — | — | — | — | — | — | — | — |
| Basaltic hornblende | 5 | 10 | 10 | 4 | 4 | — | 80 | 91 | 10 | 10 | 8 | 49 | 2 | 10 | — |
| Others | 4 | 21 | 9 | 34 | 18 | 17 | 14 | 2 | 76 | 5 | 15 | 20 | 10 | 7 | — |
| Light minerals | | | | | | | | | | | | | | | |
| Quartz | 3 | — | — | 14 | 7 | 10 | 13 | 11 | 28 | 29 | 21 | 25 | 6 | — | — |
| K-feldspar | 27 | 7 | 2 | 11 | 3 | 4 | 13 | 9 | 17 | 22 | 38 | 18 | 6 | 16 | 14 |
| Plagioclase | 69 | 92 | 97 | 74 | 89 | 85 | 74 | 80 | 55 | 49 | 41 | 57 | 88 | 80 | 79 |
| Others | 1 | 1 | 1 | 1 | 1 | 1 | — | — | — | — | — | — | — | 4 | 7 |
| Volcanic glass | 1 | — | — | 5 | — | 4 | — | trace | trace | 2 | 2 | 1 | — | 20 | 3 |
| Phytolite | trace | — | — | trace | — | trace | trace | trace | 2 | 1 | 1 | 1 | — | — | — |

1) Note: Volcanic glass and phytolite are excluded in counting the total light minerals (%).

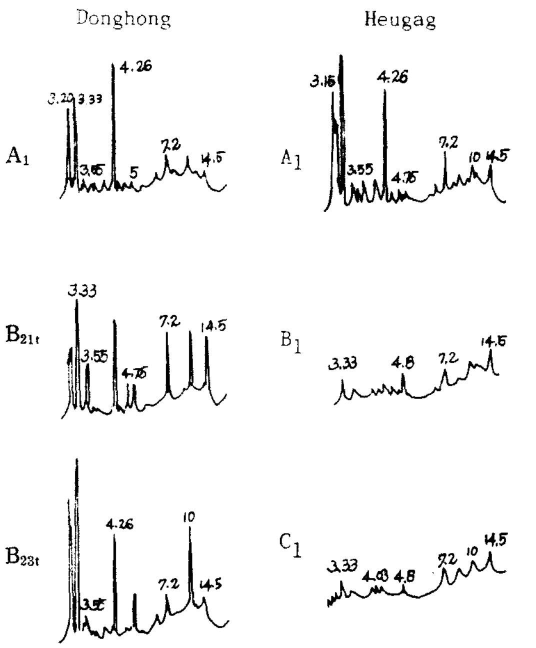



**Fig. 1.** X-ray diffraction pattern of silt fraction (2~50$\mu$m).

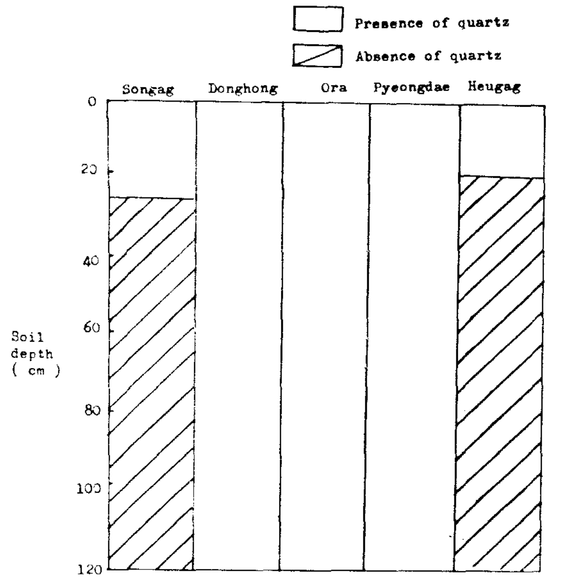



**Fig. 2.** Presence of and absence of quartz in the silt fraction.

It suggested that the surface horizon has been strongly influenced by environmental factors and subsurface has been developed on basaltic source, such as scoria beds and cinder cones.

Amorphous clay (allophane) is prevailing in the very dark brown and black soils of Ora, Pyeongdae, Heugag (Fig. 3). However, a small amount of crystalline minerals is also present in those soils. They included 14Å, 10Å and 7Å layer silicates. Allophane is easily produced from

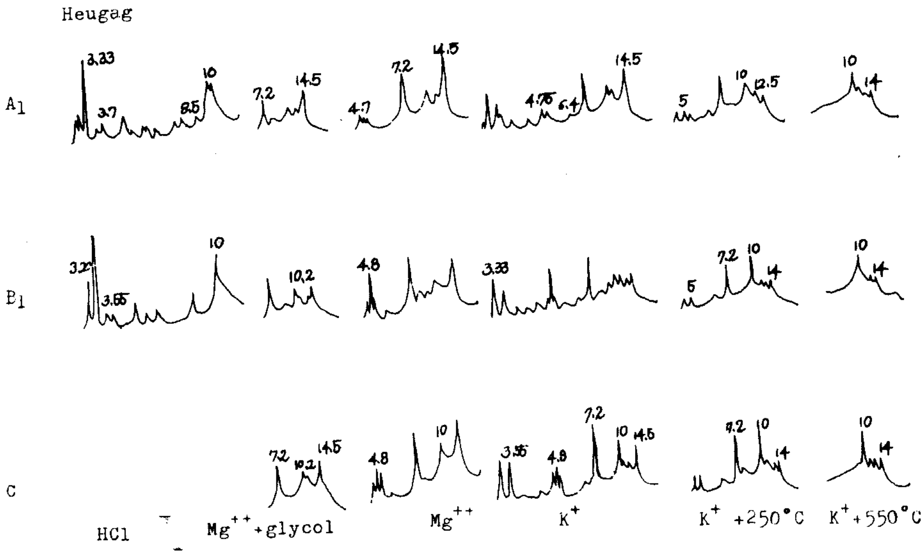



**Fig. 3.** X-ray diffraction patterns of clay fraction (0~2μm).

volcanic glass or ash which is rapidly weathered under a humid temperate climate, and is present throughout the profile in the ash soils. Imogolite is only present in the scoria layer of Heugag. Fine fiber imogolite is always associated with the globular shaped allophane (Fig. 4). The formation of imogolite is favoured by a less siliceous environment (Aomine and Mizota, 1973). The crystalline clay minerals dominate in brown to dark brown soils (Songag, Donghong) and they are 14Å, 10Å and 7Å layer silicates. 14Å layer silicates consist mainly of vermiculite and chlorite with some Al-interlayered vermiculite as a result of the high Al activity. Vermiculite is present in soils of Songag and Donghong, but chlorite is present in soils of Ora and Pyeongdae. The transformation of mica to vermiculite is a main soil forming process in soils of Songag and Donghong. The chlorite in the soils of Ora, Pyeongdae, and Heugag is probably a primary chlorite or an alteration product of ferromagnesian minerals. HCl treatment strongly decreases 14Å spacing, preserving broad reflection between 10Å and 14Å, and 7.2Å spacing is remained suggesting the presence of primary chlorite, partially weathered chlorite on irregular chlorite-vermiculite or mica-vermiculite mixed layers. Although they contain a considerable amount of mica, the evolution to vermiculite is not distinct, indicating that these black soils are relatively young. 14Å phyllosilicates are not

**Fig. 4.** Imogolite threads in clay fraction. TEM micrograph, × 53,000.

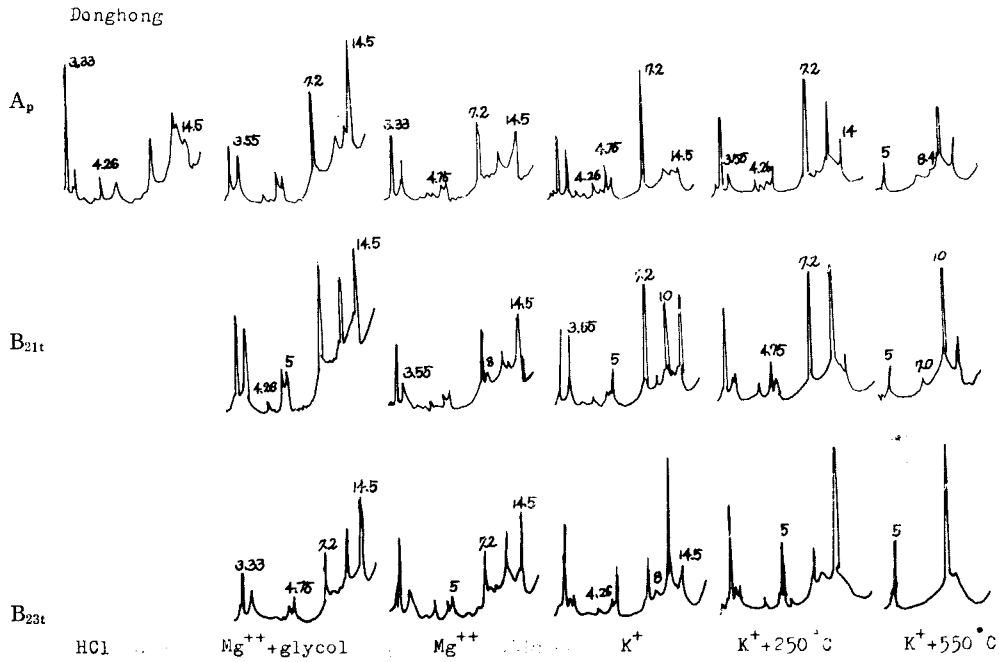



**Fig. 5.** X-ray diffraction patterns of clay fraction (0～2$\mu$m).

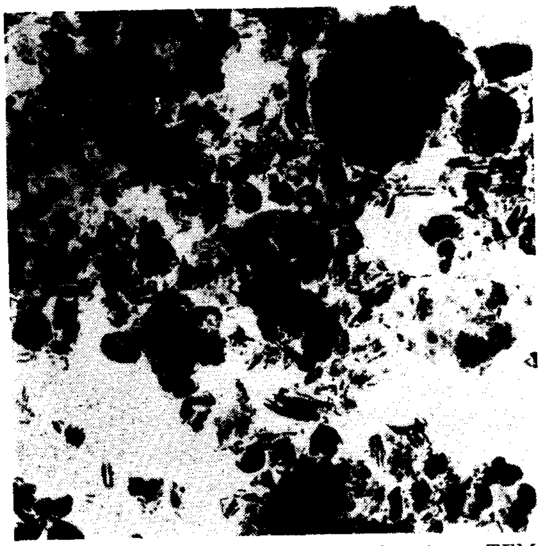


**Fig. 6.** Allophane, halloysite and mica. TEM micrograph, × 35,000.

developed out of allophane (Wada and Aomine, 1973) and their source materials are probably ferromagnesian minerals and mica (Kawasaki and Aomine, 1966). A considerable amount of mica(10Å) is present in all the soils, indicating

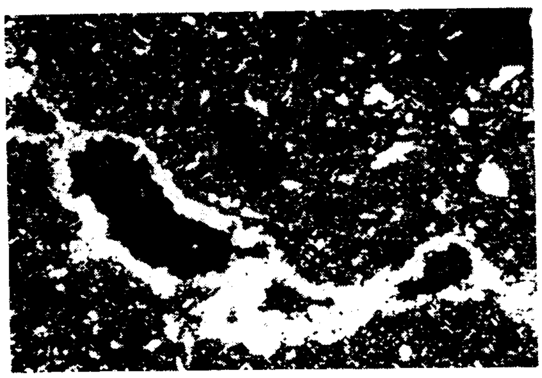
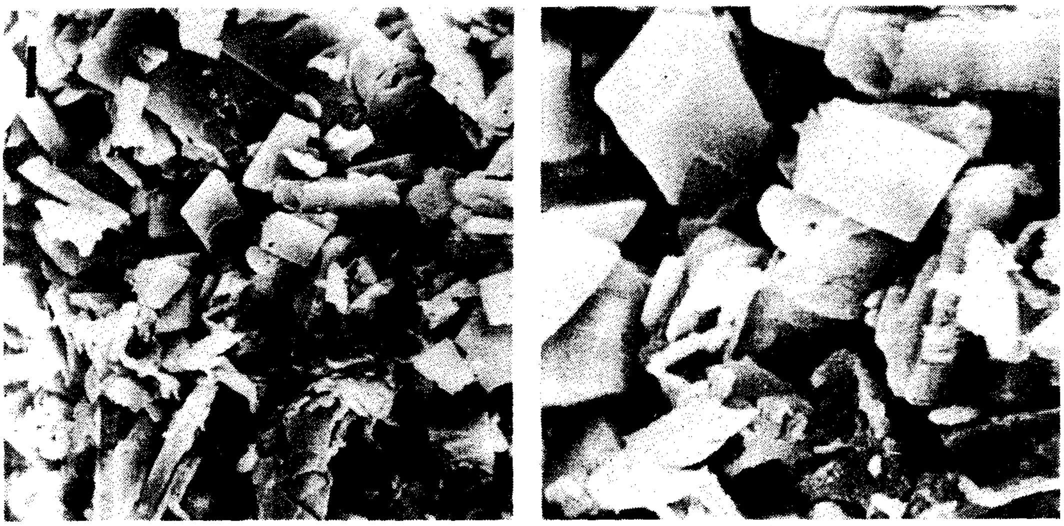


**Fig. 7.** Gibbsite in void. crossed polarizer, × 160.

that the soils have been developed on more acid ash showers and a considerable amount of quartz supports again the nature of ash materials. The presence of halloysite(7Å) can be confirmed by X-ray diffractograms (Fig. 5) and it is more abundant in the brown colour soils (Songag, Donghong) with a high silica content in the clay fraction. It forms from allophane through resilication (Aomine and Mizota, 1973) and differential weathering from volcanic ash(Aomine



(a) (b)

**Fig.** 8. Gibbsite crystals in void. SEM micrographs. (a) × 1,800, (b) × 4,500.

and Wada, 1962) (Fig. 6). Gibbsite is generally present in small amount in all the soils (Fig. 7). A large amount of gibbsite is associated with very porous scoria layers (Fig. 8, 9) and high rainfall suggesting the migration of excess aluminum along the channels (Colemet Daage, 1969). The soils can be approximately grouped into two categories based on chemical analysis of their clays (Table 2). Songag and Donghong have a relatively higher $SiO_2$ and a lower $Al_2O_3$ content than soils of Pyeongdae and Heugag which contain more free and lattice aluminum. This difference can be explained by composition of parent material and age.

Soils developed at the near coast are probably older than soils situated at Mt. foot slope of Halla and have an argillic horizon. $SiO_2/Al_2O_3$ molar ratios are comparatively large in soils of Songag and Donghong and become smaller with increasing altitude, indicating that the amorphous constituents may increase with altitude. A considerable amount of iron is present in the clay fractions after removal of free iron oxides, suggesting that the soil contains iron bearing minerals such as chlorite, mica (biotite) and

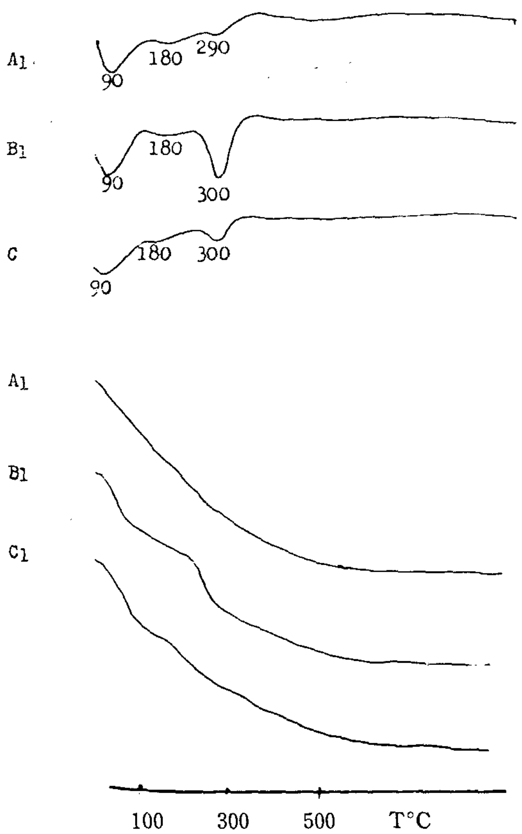



**Fig.** 9. DTA and TGA curves of clay fraction of Heugag series.

**Table 2.** Chemical composition of clay (0~2$\mu$m). (%)

| Soil name | Horizon | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | $K_2O$ | $SiO_2/Al_2O_3$ |
|---|---|---|---|---|---|---|---|
| Songag | A1 | 39.24 | 29.65 | 13.20 | 0.63 | 1.30 | 2.38 |
| | B21t | 38.18 | 31.14 | 12.16 | 1.63 | 1.76 | 2.21 |
| | B22t | 38.36 | 32.97 | 11.29 | 1.28 | 1.95 | 2.09 |
| | B23t | 36.56 | 33.85 | 11.20 | 2.76 | 2.08 | 1.94 |
| Donghong | A1 | 40.55 | 29.08 | 10.94 | 1.01 | 2.88 | 2.50 |
| | B1t | 41.28 | 28.55 | 11.84 | 1.06 | 2.83 | 2.60 |
| | B21t | 42.87 | 28.70 | 10.55 | 1.06 | 3.10 | 2.69 |
| | B22t | 41.30 | 28.70 | 10.15 | 1.01 | 3.16 | 2.59 |
| | B23t | 41.83 | 26.70 | 12.36 | 1.21 | 3.32 | 2.82 |
| Ora | A1 | 31.84 | 32.24 | 12.11 | 1.07 | 2.73 | 1.77 |
| | A3 | 31.07 | 31.70 | 12.15 | 1.00 | 3.02 | 1.76 |
| | B1 | 31.66 | 32.46 | 11.51 | 1.02 | 2.92 | 1.76 |
| | B2 | 31.39 | 32.10 | 12.04 | 1.21 | 3.51 | 1.76 |
| | B3 | 30.27 | 32.70 | 12.22 | 1.20 | 3.06 | 1.67 |
| Pyeongdae | A11 | 24.90 | 30.24 | 12.67 | 0.77 | 2.22 | 1.48 |
| | A12 | 24.41 | 31.00 | 13.50 | 0.68 | 1.90 | 1.41 |
| | B1 | 23.34 | 32.21 | 13.33 | 0.81 | 2.12 | 1.30 |
| | B2 | 23.01 | 33.09 | 12.67 | 0.95 | 2.44 | 1.25 |
| | B3 | 22.36 | 34.09 | 12.04 | 0.94 | 2.17 | 1.18 |
| Heugag | A1 | 24.59 | 30.64 | 15.09 | 1.44 | 1.94 | 1.44 |
| | B1 | 22.33 | 32.19 | 16.81 | 1.18 | 1.81 | 1.24 |
| | B2 | 23.91 | 33.03 | 16.28 | 1.51 | 1.58 | 1.30 |
| | B3 | 24.38 | 32.48 | 15.71 | 0.87 | 2.51 | 1.35 |
| | C | 23.73 | 32.68 | 14.99 | 1.12 | 2.05 | 1.31 |

vermiculite. The presence of Ca and Na suggests that the soils contain feldspar. It is also noticeable that the water content of dehydration and dehydroxylation markedly increases with altitude and this increase may be related to the presence of amorphous constituents.

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