Rates and mechanism of weathering-rind development on andesite gravel in fluvial terrace deposits

Abstract

In an attempt to explore the rates and mechanism of weathering-rind development, temporal changes in several rock properties due to weathering were investigated and a growth model for the weathering rinds was constructed. The study area is Nasuno-ga-hara, Central Japan, which consists of coalescing alluvial fans with four fluvial terraces and a modern floodplain. The formation ages of these geomorphic surfaces are 0-ka, 20 ka, 320 ka, 450 ka and 830 ka. The time elapsed since the above ages is assumed as the weathering periods. The terrace and floodplain deposits commonly include andesite gravel. The gravel was randomly sampled from the outcrops of each geomorphic surface. All the gravel taken from 320-ka, 450-ka and 830-ka terraces has brown weathering rinds (brown layers) with a thickness of 3-6 mm, which differ from fresh-looking inner parts with gray colour. Rock samples with similar texture were chosen for detailed investigation. The rocks taken from each geomorphic surface are called as 0-ka, 20-ka, 320-ka, 450-ka and 830-ka rocks.

Mineralogical, chemical, physical and mechanical properties as well as apparent thickness and colours of the rocks were investigated. Average apparent thickness of brown layers for 0-ka rocks is null, that for 20-ka rocks is 0.7 mm, that for 320-ka is 2.9 mm, that for 450-ka is 3.8 mm, and that for 830-ka is 5.6 mm. Colours were measured quantitatively using visible microspectrometer. The results show that the colour-system values of L*, a* and b* for the brown layers are markedly large, whereas those for the inner parts are small and almost constant. L*-values for the inner parts of some samples decrease with increasing depth from rock surface. Microscopic observation and XRD analysis indicate that inner parts of the rocks consist of quartz, tridymite, plagioclase, pyroxene and

magnetite. In contrast, brown layers of 320-ka, 450-ka, and 830-ka rocks contain kaolin minerals, smectite, maghemite and hematite. The XRD charts show that the peak heights for plagioclase and pyroxene in the brown layers are smaller than those for the inner parts.

Bulk-chemical compositions for both the brown layers and the inner parts of each rock were determined by XRF analysis. The results indicate that the brown layers have small contents of SiO_2, Al_2O_3, Sr and alkali/alkaline earth metals but large contents of H_2O, TiO_2 and $FeO+Fe_2O_3$. The concentration maps of nine major elements based on EPMA analysis also show that Ca is much more depleted than other elements. The ICP analysis also indicates that TiO_2, $FeO+Fe_2O_3$, V and Zr are more abundant in the brown layers, whereas Al_2O_3, Sr, and alkali/alkaline earth metals are less abundant in inner parts The content of MnO, P_2O_5, As, Ba, Co and Li tend to be constant irrespective of change in depth. CaO, Sr, Ni, Cr and Cu are depleted from deeper points than other elements, although the amounts of these elements in the inner parts originally differed depending on samples.

The measurements of pore-size distribution show that pore volume and porosity for the brown layers are larger than those for the inner parts. In contrast, bulk density for the brown layers are smaller than that for the inner parts. Vickers microhardness (VHN values) show that the brown layers between 0 mm and a few millimeter depth from the rock surface have extremely low hardness (Zone I). The hardness for some samples increases drastically with increasing depth (Zone II) and then reaches high and constant values of *ca.* 500-700 gf/μm^2 (Zone III). The hardness for some other samples increases slowly with increasing depth and does not attain a constant value, indicating that these samples lack Zone III.

Using the averages of measured values, the changing rates of some rock

properties of the weathering rinds were compared, with the assumption that the values for 0-ka and 830-ka rocks are 100 and 0, respectively. The apparent thickness has the lowest decreasing rate. Similarly, chemical index of alteration (CIA) or the dissolution degree of alkali/alkaline earth metals decreases slowly with time. In contrast, VHN values decreases drastically during the early stage of weathering. The values for 320-ka rocks are already as small as those for 450-ka and 830-ka rocks. These observations indicate that rock hardness decreases faster than chemical composition with the progress of weathering.

Based on the relations between rock properties and depth from the rock surface, two zones of weathering rinds are defined. *Zone A* corresponds to the brown layer, which is characterized by large Fe contents and high a*- and b*-values. This zone experienced both oxidization and dissolution. The oxidation of Fe accounted for the brown colour. Ignition loss for the zone is notably large, indicating the effects of hydration or hydrolysis. This zone also corresponds to Zone I determined by the VHN measurement. *Zone B* corresponds to both the white layer and inner Zone II identified from the VHN measurement. It is characterized by the dissolution of Sr and alkali/alkaline metals. The inner border of this zone is located at the place where the amounts of Ca and Sr as well as VHN values start decreasing with decreasing depth.

The formation of the two zones can be explained from change in the directions of water flux. Alkali/alkaline earth metals dissolve when water is supplied from matrix to a rock particle. Then, the dissolved metals move out of the rock due to outward water flux while the subsurface water table is low. Thus, the amounts of most metals decrease in Zone A+B. However, iron tends to precipitate in Zone A because the ferric hydroxides such as FeO(OH), $Fe(OH)_3$ and Fe_2O_3 accumulates. Therefore, the zone has distinguishable brown colour.

A growth model of weathering rinds in andesite rocks was proposed. The total thickness of the two zones (L_{A+B}) is related to both rock porosity (n) and time (t), whereas the thickness of Zone A (L_A) is basically independent on porosity. Their relations can be represented by diffusive equations: $L_{A+B} = 0.2571 (n \cdot t)^{1/2}$ and $L_A = 0.1348 \cdot t^{1/2}$.

Key words: weathering rate, weathering rind, dissolved zone, oxidized zone, colour measurement, pore-size distribution, Vickers microhardness, Nasuno-gahara.