Rates of rock property changes due to weathering: welded tuff gravel in fluvial deposits in the Miyazaki Plain, Japan

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Abstract

Temporal changes in color and physical properties due to weathering during 240 ka were examined using welded tuff gravel in fluvial terrace deposits with a known emergence time that were distributed in Miyazaki Plain, Japan. The time between the age of each terrace formation (8, 90, 120 and 240 ka) and the present was assumed to be the weathering period.

The results of the measurements are as follows: (1) rock samples have both the outer weathered layers and inner fresh parts. The outer weathered layers can be subdivided into two parts, outer weathering rind and inner weathering rind. (2) the *a**, *b**-values of color indices increase as the weathering period increases. (3) effective porosity increases during 0 to 90 ka. These results suggest that (1) the increase in pores in gravel that occurs as the weathering period increases is caused by the dissolution of biotite; (2) iron concentration and the formation of goethite occur in older gravels. Dissolution of biotite and increasing pore volume play major roles in the weathering of welded tuff.

Keywords: Weathering, Welded Tuff, Osuzu Acidic Rocks, Miyazaki Plain, Rock Properties, Color Measurement

1. Introduction

Weathering influences the processes and rates of landform development. The study of these processes and rates of rock weathering is, therefore, important for engineering Geology. Studies on the changing rates of rock properties due to weathering have been limited in number (Kimiya, 1975; Crook and Gillespie, 1986; Oguchi, 1999 ; Oguchi et al. 1999; Hachinohe, et al., 1999; Oguchi and Matsukura, 1999; Nishiyama and Matsukura, 2006), because of difficulties in estimating weathering periods. In order to solve the rates and mechanism of welded tuff weathering, this study investigates the rock properties of welded tuff gravel taken from terrace deposits in a series of dated fluvial terraces in the Miyazaki Plain, south Kyushu, Japan. Welded tuff gravel included Middle Miocene Osuzuyama Volcano-Plutonic Complex. The rates of long-term weathering are estimated based on the assumption that the weathering period is equal to the period between the age of emergence of these terraces and the present. This study can discuss the changes in rock properties due to weathering during 240 ka. The measured rock properties include the following: (1) rock texture (observation of nacked eye), (2) colors, (3) physical properties (effective porosity and apparent specific gravity), Using these data, the relationships between rock properties and weathering period in an attempt to clarify the rates and mechanism of weathering of welded tuff gravel.

2. Geological Features of Sampling Points and Rock Samples for Analysis

The welded tuff rock was sampled from fluvial terrace deposits in Miyazaki Plain, Kyushu. Miyazaki Plain has the best-developed middle to late Quaternary deposits in Kyushu. The stratigraphy of this plain has been investigated using tephrochlonology in previous studies (e.g., Nagaoka et al., 2010). This study assumes that fresh rocks were deposited on river floodplains and their weathering started soon after the terrace emergence. Thus, the time between the age of each

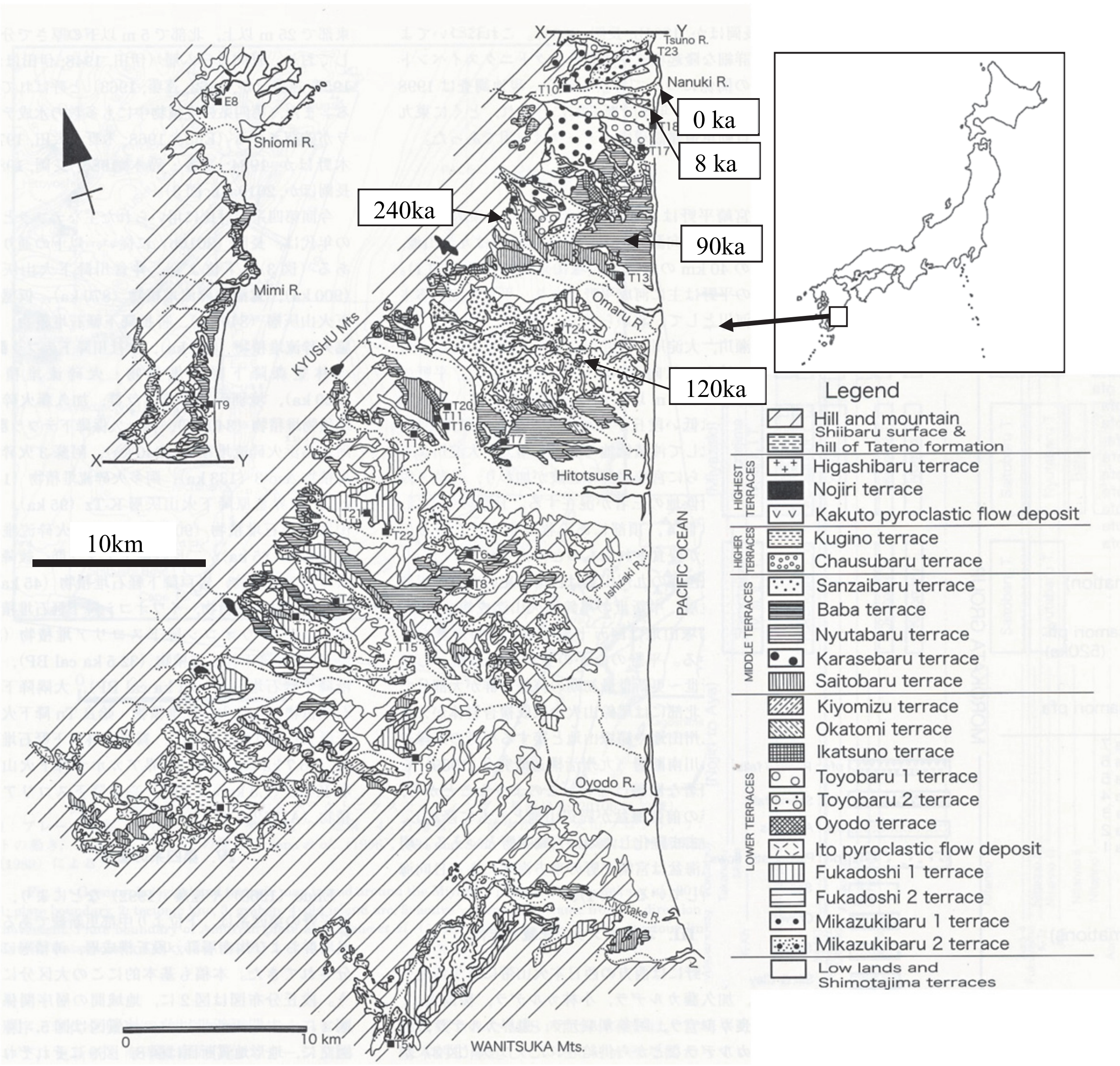

Fig. 1 Geomorphological map of the Miyazaki Plain and sampling points (After Nagaoka et al, 2010)

terrace formation and the present can be assumed to be the weathering periods.

The locations of the eight rock sampling sites are shown in Figs 1 and 2. All sampling points are directly covered with tephra layers, except for the recent river floodplain. All sampling points at each site are above the groundwater level.

All examined welded tuff gravel belongs to the Middle Miocene Osuzuyama Volcano-Plutonic Complex. All welded tuff gravel samples are biotite rhyolite welded tuff with smaller amounts each sampling point. The characteristics of the sampling sites and welded tuff gravel sample taken from the sampling sites are as follows:

(1) *Recent river floodplain (0-ka rocks)*: The sampling point is located on a gravel bar of river floodplain in the Nanuki River. The gravel taken from this site is not visibly weathered. The cutting surface of this gravel shows that it is dark gray colored and has no weathering rind. This gravel is hard, and sounds made by hammer blows to it are clear.

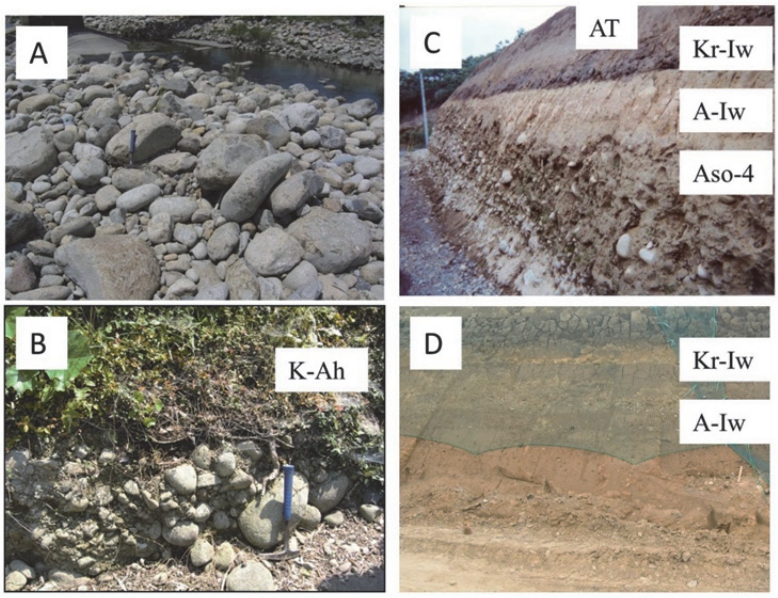

Fig.2 Sampling sites.
A: Present river floodplain (0ka),
B: Mikazukibaru terrace deposits (8ka),
C: Karasebaru terrace deposits (90ka),
D: Sanzaibaru terrace deposits (120ka),
E: Chausubaru terrace deposits (240ka)

(2) *Mikazukibaru terrace deposits (8-ka rocks)*: Gravely deposits of this sampling point are almost directly covered by the tephra K-Ah (0.73 cal ka BP) and black humic soils. The covering tephra layer is about 0.3 m thick. The gravel taken from this point is slightly weathered, and its color is light gray. This gravel has no weathering rind. It is hard, and sounds made by hammer blows to it are clear.

(3) *Karasebaru terrace deposits (90-ka rocks)*: Gravely deposits of this sampling point are almost directly covered by the tephra Aso-4 (90 ka). The covered tephra layer is about 5 m thick. The gravel taken from this site is slightly weathered, and its color is light gray to brown. This gravel is brittle, and sounds made by hammer blows to it are somewhat dim.

(4) *Sanzaibaru terrace deposits (120-ka rocks)*: Gravely deposits of this sampling point are almost directly covered by the tephra A-Iw (70 ka). The covered tephra layer is about 5 m thick. Deposits contain the tephra Aso-3 (120 ka) in the Lower part at the type locality. The gravely deposits are correlated with the non-marine upper member of the Sanzaibaru formation. The gravel taken from this site is strongly weathered, and its color is brown to reddish brown. This gravel is brittle, and sounds made by hammer blows to it are dim.

(5) *Chausubaru terrace deposits (240-ka rocks)*: Gravely deposits of this sampling point are almost directly covered by the tephra Kr-Iw (40-50 ka). The covered tephra layer is about 3 m thick. Deposits contain the tephra Ata-Th (240 ka) in the middle part at the type locality. The gravel taken from this site is strongly weathered, and its color is reddish brown. This gravel is brittle, and sounds made by hammer blows to it are dim.

3. Analysis and results

3.1 Rock Texture

Figure 3 lists the characteristics of the rock based on naked-eye observations of cutting surfaces. Each sample has a fresh-looking interior with some phenocrysts of quartz, plagioclase and biotite. The observations of the cutting surface of rock with the naked-eye are summarized as follows:

(1) 0- and 20-ka rock samples have fresh textures through the rock surface to the interior. They have white phenocrysts of quartz and plagioclase and black phenocrysts of biotite surrounded by a grey groundmass. No weathering rind can be observed at the cutting surface of rock samples. The appearance of quartz, plagioclase and biotite phenocrysts have not changed.

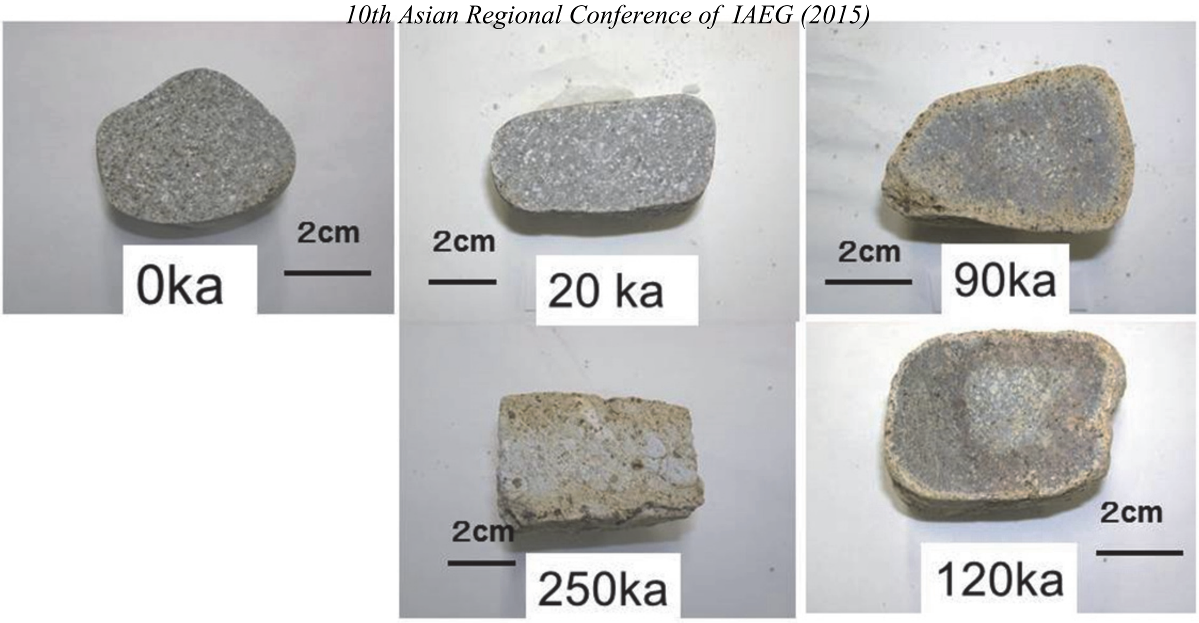

Fig. 3 Some of the selected cut-rock samples.

(2) 90- and 120-ka rock samples have both the outer weathered layers and inner fresh parts. The outer weathered layers can be subdivided into two parts, outer weathering rind and inner weathering rind. The thickness of outer weathering rind is 4-8mm, inner weathering rinds is 10-15 mm. Although the appearance of quartz phenocrysts has not changed, plagioclase and biotite has been slightly weathered.

(3) 240-ka rock samples have outer weathering rind only. The thickness of outer weathering rind is 10-15 mm. Although the appearance of quartz phenocrysts has not changed, plagioclase and biotite has been slightly weathered.

3.2 Color

Soil color is closely related to the content of goethite and hematite (e.g., Torrent et al., 1982). Recent researchers in earth sciences have used a spectrophotometer to measure the color of rocks, minerals and soils (e.g., Nagano and Nakashima, 1989; Nakashima et al., 1992; Nakashima, 1994; Oguchi et al., 1995; Mitsushita et al., 1998; Wakizaka et al., 1998; Nishiyama et al, 2011).

The color of rock samples were determined using a Conica-Minolta SPAD-503 Spectrophotometer as having components $L*$, $a*$ and $b*$, i.e., $L*$ $a*$ $b*$ color space. The $L*$-value is the degree of lightness: $L* = 0$ corresponds to black, and $L* = 100$ corresponds to white. A positive value of $a*$ expresses red, and a negative value green. A positive value of $b*$ indicates yellow, and a negative value blue. Positive $a*$- and $b*$-values express an increase in iron minerals such as goethite and hematite (Nakashima et al., 1992; Nakashima, 1994). Color measurements were carried out on a surface and cutting interior of each rock sample taken from each sampling site.

The results of color measurements arranged by weathering time are shown in Table 1. The number in the parenthesis is standard deviation. The $L*$-value ranges from 51.5 to 62.6, the $a*$-value ranges from 1.6 to 5.6, and the $b*$-value ranges from 11.1 to 18.7. The $a*$ and $b*$-values increases during increasing weathering periods, and the $L*$-value has no trend during increasing weathering period. These results support that the color of rock samples becomes more yellowish during the 240-ka period.

The $a*$-$b*$ diagram (Fig. 4) shows that outer weathering rinds are reddish than interior of rock samples. The gradient of the trend line from all plotted data is linear.

Nakashima (1994) suggested that an increase in the $b*$-value expressed an increase in goethite and an increase in the $a*$-value expressed an increase in hematite. Therefore, the present data of color measurement indicate that goethite increases at the outer weathering rinds during the 240-ka period.

Table 1 apparent specific gravity, effective porosity and color values of rock samples.

weathering time	number of samples	apparent specific gravity, *Gn*	effective porosity *ne* (%)	*L**	*a**	*b**
0 ka (surface)	11	2.56 (0.04)	3.7 (1.3)	59.0 (2.4)	1.6 (0.5)	11.1 (1.4)
0 ka (interior)				53.9 (4.1)	1.1 (1.2)	7.3 (3.2)
the difference between the color values of surface and interior				5.1	0.5	3.8
8 ka (surface)	12	2.48 (0.08)	6.2 (2.3)	51.5 (4.4)	2.7 (0.8)	11.6 (2.7)
8 ka (interior)				52.2 (3.9)	1.1 (1.0)	7.0 (2.3)
the difference between the color values of surface and interior				-0.7	1.6	4.6
90 ka (surface)	10	2.23 (0.15)	13.2 (4.5)	59.1 (2.9)	5.6 (1.2)	18.7 (2.5)
90 ka (interior)				54.5 (5.3)	1.8 (1.3)	9.1 (4.8)
the difference between the color values of surface and interior				4.6	3.8	9.6
120 ka (surface)	8	2.35 (0.09)	10.3 (2.9)	62.6 (3.9)	4.3 (1.4)	16.8 (2.2)
120 ka (interior)				56.9 (9.8)	0.8 (1.1)	5.5 (2.8)
the difference between the color values of surface and interior				5.7	3.5	11.3
240 ka (surface)	10	2.41 (0.11)	8 (2.8)	52.4 (2.8)	5.0 (1.3)	14.4 (1.8)
240 ka (interior)				54.8 (4.6)	1.6 (1.0)	6.8 (3.5)
the difference between the color values of surface and interior				-2.4	3.4	7.6

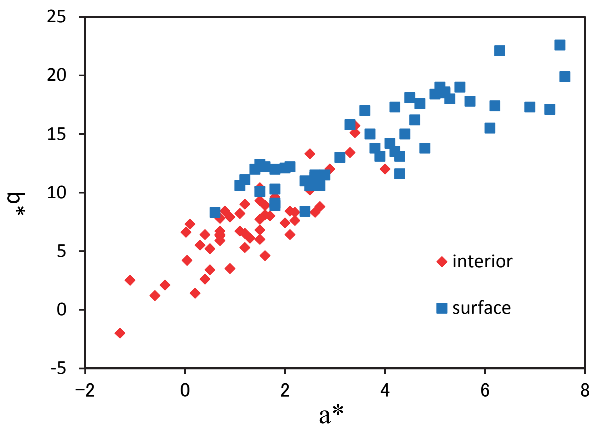

Fig. 4 a*-b* diagram

3.3 Physical Properties

The effective porosity, n_e (%), and the apparent specific gravity, G_n, are widespread indices for physical properties of rocks. The methods of analysis were used by the Japanese Geotechnical Engineering Society (1989). The measurements were carried out using 8 to 12 samples taken from each sampling site.

Temporal changes in the effective porosity and the apparent specific gravity are shown in Table 1. The effective porosity ranges from 3.7 to 13.2 %, and the apparent specific gravity ranges from 2.23 to 2.56. The effective porosity increases during 0 to 90 ka, while the specific gravity decreases during 0 to 90 ka.

4. Mechanism of Weathering in welded tuff Gravel

Naked-eye observation on cutting surface of rock sample show that 90-, 120-, and 240-ka rocks have weathering rinds. The weathering rinds are subdivided into two zones based on naked-eye observation, outer weathering rinds and inner weathering rinds. The color of welded tuff gravel changes to yellowish or reddish as the weathering period increases. The color of rocks is affected by the iron minerals contained therein (Nakashima et al, 1992). This suggests that when welded tuff becomes reddish due to weathering, it is caused by an increase in iron minerals such as goethite and hematite. Fe^{2+} is formed by leaching of biotite due to weathering. Fe^{2+} is easily oxidized to Fe^{3+} in an oxidative environment such as in terrace deposits. Fe^{3+} is precipitated within the rock because Fe^{3+} has a low solubility in natural water. Hydroxides such as ferrihydrite are formed by precipitation of Fe^{3+}. The results of color measurement suggest that iron minerals in rock samples change from ferrihydrite to goethite (α-FeOOH) during the 240-ka period. Based on the results of naked-eye observation, iron originates from biotite in welded tuff gravel. Changing iron by oxidation, hydration and mineralization during weathering ultimately produces goethite. The rock structure and color of welded tuff gravel seem to be affected by changes of iron minerals.

5. Conclusions

Temporal changes in color and effective porosity due to weathering during 240 ka were examined using welded tuff gravel in fluvial terrace deposits with a known emergence time that were distributed in Miyazaki Plain, Japan. The results of the measurements are as follows: (1) rock samples have both the outer weathered layers and inner fresh parts. The outer weathered layers can be subdivided into two parts, outer weathering rind and inner weathering rind. (2) the *a*, b**-values of color indices increase as the weathering period increases. (3) effective porosity increases during 0 to 90 ka. These results suggest that (1) the increase in pores in gravel that occurs as the weathering period increases is caused by the dissolution of biotite; (2) iron concentration and the formation of goethite occur in older gravels. Dissolution of biotite and increasing pore volume play major roles in the weathering of welded tuff.

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