Physical, Chemical and Mineralogical Properties of Weathering Crust of Granitic Rocks Distributed in Antioquia, Colombia

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コロンビア国アンティオキア花こう岩体風化殻の
物理的, 化学的, 鉱物学的性質

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Abstract

The weathering crust of granitic rocks in Antioquia, Colombia, can be divided into eleven zones. Since zone IX that has been formed by wind-bourne loess is not a weathering crust in situ, it was excluded from the study. Zones X and XI, being soil, were also excluded. The grain distribution was mechanically analyzed for the samples from zones V-VIII. The change from "masa" A (zone V) to "masa" B (zone VI) is characterized by transformation of pebble to sand, the change from "masa" B to red "masa" (zone VII) is characterized by transformation of silt to clay and the change from red "masa" to "shimofuri" clay (zone VIII) which does not show noticeable alteration of the silt-size grains to clay-size grains is characterized by transformation only of sand to silt.

Mineralogical composition of weathering zones are identified by the X-ray diffraction method. The presence of quartz was confirmed in all the weathering zones. K-feldspar begins to alter from weathered granite A (zone III) and completely disappears in "masa" A. Plagioclase and biotite disappears almost completely in the initial stage of weathering. Of the secondary minerals by the weathering action, chlorite, illite, halloysite and gibbsite are seen. The existence of kaolinite is observed very conspicuously in red "masa" and "shimofuri" clay.

Chemical analysis was carried out by X-ray fluorescence spectrometer. The transfer of CaO and Na₂O shows the tendency of decrease in a convex-shaped curve in the weathering crust in Japan but in a concave-shaped curve in Colombia. The transfer of K₂O and MgO shows almost no change in the weathering crust in Japan but a tendency of rapid decrease in Colombia in "masa" B. SiO₂ decreases with the progression of weathering but resumes an increase in red "masa". This also well corresponds with the presence of gibbsite until "masa" B which transforms to kaolinite in red "masa". Although literatures have shown that the progression of weathering induces reduction of SiO₂ with the result of final formation of gibbsite, the new finding obtained in the present study shows that further progression of weathering to red "masa" or "shimofuri" clay induces, on the contrary, infusion of SiO₂ with the consequence of kaolinite formation from gibbsite.

INTRODUCTION

The author had an opportunity to make a survey of weathering of granitic rocks distributed in the vicinity of Medellin, Colombia in 1976-1977. These granitic rocks are called Antioquia batholith dis-

tributed extensively on a low-relief surface at an altitude of 2,100 to 2,500 m, having a thick weathering crust of 50-100 m in thickness. This district belongs climatologically to the tropical humid climate.

As the topographic conditions of weathering crust and zoning of weathering profile have already been reported (KIMIYA, 1978), this paper describes the physical, chemical and mineralogical changes in

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weathering crust together with discussion on the difference in the weathering crust of the Japanese granitic rocks.

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LOCATION AND OUTCROPS

The weathering crust of granitic rocks including soil in Antioquia can be divided into 11 zones (KIMIYA, 1978): Zone I, granite A (parental fresh granites); Zone II, granite B (slightly weathered granites); Zone III, weathered granite A (moderately weathered granites); Zone IV, weathered granite B (highly weathered granites); Zone V, "masa" A; Zone VI, "masa" B; Zone VII, red "masa"; Zone VIII, "shimofuri" clay; Zone IX, loess; Zone X, white or reddish brown soil and Zone XI, black soil. Of the above zones, since zone IX that has been formed by wind-bourne loess is not a weathering crust in situ, it was excluded from the study. Zones X and XI, being soil, were also excluded. Therefore, the samples from zone I to zone VIII were used in this study.

The samples of zones I-IV and VII-VIII were collected from the outcrops in the vicinity of San Pedro located approximately 25 km north of Medellin. The samples of zones V and VI were collected from the outcrops distributed in Yarumal which is located approximately 80 km north of Medellin (Fig. 1).

Observation of the outcrops from where these samples were taken are as follows.

Zone I (granite A): The outcrop formed only with a fresh granite at an altitude of 2,400 m on the east of San Pedro. The altitude of the low-relief surface around this area is 2,500-2,600 m and the outcrops are placed in the erosional valley produced by erosion of the low-relief surface by approximately 150 m. The granite is very hard and entirely free from the effect of weathering.

Zones II (granite B), III (weathered granite A) and IV (weathered granite B): The outcrop on a large quarry situated at an altitude of 2,450 m toward

Fig. 1 Topographic map in the vicinity of Medellin.

San Pedro from the outcrop from which zone I sample was taken. As biotite among some of the rocks in this outcrop was only observed stained with iron rust, the sample that did not appear much different from that obtained from zone I was collected as the sample for zone II. The sample collected from zone III (weathered granite A) still retained hardness that could be penetrated by a nail driven by a hammer. Plagioclase assumed lusterless white and biotite was so altered that could be broken easily. The sample from zone IV (weathered granite B) was reduced into sands by the light stroke of a hammer and it was impossible to obtain a hand-specimen as a mass. Plagioclase and biotite were in such a brittle state that they could be crumbled easily by fingers.

Zones V ("masa" A) and VI ("masa" B): Samples were collected from the outcrops of 7-8 m in width and 4 m in height in Yarumal. The outcrop here consists mostly of reddish coloured "masa" A, sporadically dotted with pseudomorphs of core stones composed of "masa" A. "Masa" A assumes a whitish colour with well preserved original texture of a granite. Plagioclase and biotite are slightly altered. "Masa" B also has well preserved original texture of a granite. Argillitization of plagioclase and biotite advanced so extensively that crushing by fingers turned them into plastic clay.

Zones VII (red "masa") and VIII ("shimofuri"

* The term "masa" is in common use in Japan, which refers to loosely decomposed granites with an appearance of sand. "Masa" is here defined as an loosely decomposed granite due to weathering in situ. It forms generally a steep cliff, but crumbles easily by running water and also by a slight shock.

clay): Samples were collected from the road-cut exposure on the road that connects Medellin with San Pedro. Red "masa" is generally reddish in colour. As a result of considerable argillitization of plagioclase and biotite, grasping in hand could transform red "masa" into a clod. While the original texture of a granite is preserved in red "masa", it is not in "shimofuri" clay. "Shimofuri" clay is composed of red and yellow clay in a mottled effect similar to spotting of a "shimofuri" beef. "Shimofuri" clay is not sediments but residual clay weathered in situ.

GRANULAR VARIATION

As samples from zones I-IV did not permit mechanical analysis, the grain distribution was mechanically analyzed for the samples from zones V-VIII. A sieve was used for the grains of the size above $4\phi^*$ and a hydraulic elutriation was used for those of the size below 4ϕ . Granular variations drawn in a cumulative curve are shown in Fig. 2. The weight percentages of pebble, sand, silt and clay are shown in Fig. 3. The grain sizes of pebble, sand, silt and clay are given a definition by Wentworth (1922). The cumulative curve moves from a coarser grain to a finer grain, as weathering progresses, namely, formation of the order of "masa" A, "masa" B, red "masa" and "shimofuri"

Fig. 2 Granular variations drawn in a cumulative curve.

* $\phi = -\log_2 d$ where d is grain size in millimeter.

Fig. 3 Variation of the proportion of pebble, sand, silt and clay grains in zone V-VIII.

clay from left to right in the figure. Moreover, the curve assumes a shift from a convex to a concave with the progress of weathering. This indicates that the progression of weathering transforms the crust from coarse grain formation to fine grain formation.

Variation of the proportion of pebble, sand, silt and clay grains in each zone was then examined (Fig. 3). The change from "masa" A (zone V) to "masa" B (zone VI) causes rapid reduction of the pebble-size grains from 25.7% to 1.1%. In other words, most of the pebble-size grains contained in "masa" A were transformed into sand-size grains. Concomitantly approximately 1/4 of the sand-size grains were reduced to silt-size grains. However, when "masa" A was changed to "masa" B, it was only 2% of the silt-size grains that was transformed into clay-size grains. The change of a little less than 1/2 of the sand-size grains to silt-size grains and concomitantly more than 1/2 of the silt-size grains to clay size grains occurred as a result of the change from "masa" B to red "masa" (zone VII). Namely, the clay-size grains which were only 4.3% in "masa" B largely increased to 18.8% in red "masa". The change from sand-size grains to silt-size grains also occurred by the change from red "masa" to "shimofuri" clay (zone VIII), where, however, the change from the silt-size grains to clay-size grains was not so significant. Therefore, "shimofuri" clay contains as much as 62% silt-size grains.

Summarizing the above results, the change from "masa" A to "masa" B is characterized by transformation of pebble to sand, the change from "masa" B to red "masa" is characterized by transformation of silt to clay and the change from red "masa" to "shimofuri" clay which does not show noticeable alteration of the silt-size grains to clay-size grains is characterized by transformation only of sand to silt.

MINERALOGICAL COMPOSITION OF WEATHERING ZONES

The grains of the size below 8ϕ (below 7ϕ for some of the samples) were separated from the 8 samples of zone I to zone VIII in distilled water by hydraulic elutriation for identification of clay materials by the X-ray diffraction method. The methods proposed by OINUMA et al. (1961), and OINUMA and KODAMA (1967) were used. The mineral contents other than clay materials were identified by microscopic observation, and X-ray diffraction examination of the bulk. The results obtained are shown in Fig. 4. The presence of quartz, a primary

Fig. 4 Mineral compositions in weathering zones.

mineral, was confirmed in all the weathering zones from the fresh granite to "shimofuri" clay, and the diffraction pattern suggested almost no alteration of quartz. K-feldspar begins to alter from weathered granite A (zone III) and completely disappears in "masa" A (zone VI). Plagioclase begins to alter from granite B (zone II) and completely disappears in "masa" B. Biotite disappears almost completely in weathered granite A. Of the secondary minerals by the weathering action, chlorite and illite, on the other hand, are contained from weathered granite B to "masa" A (zone V) and halloysite exists only in weathered granite B. Gibbsite is seen to appear from weathered granite A, subsequently making more conspicuous appearance gradually but disappears in red "masa" (zone VII). The existence of kaolinite is observed partially in weathered granite A, more frequently in weathered granite B and very conspicuously in red "masa" and "shimofuri" clay (zone VIII).

Extracting only plagioclase and biotite, they were examined by X-ray diffraction, which showed that plagioclase was altered to illite in zones from weathered granite A, to halloysite in weathered

granite B, to gibbsite and kaolinite in "masa" A and totally to gibbsite and kaolinite in "masa" B. Biotite, when weathered into weathered granite A, is altered mostly to chlorite and vermiculite and partly to kaolinite and gibbsite. Biotite altered to chlorite and vermiculite is further altered entirely to kaolinite and gibbsite in "masa" B. Gibbsite is presumed to be altered to kaolinite in red "masa" and "shimofuri" clay. Comparison of the above results with the data obtained by KIMIYA (1975) in his study on the weathering crust of granitic rocks distributed in Mikawa Highland discloses similarities as well as dissimilarities. The existence of quartz in all the zones and disappearance of plagioclase in "masa" represent close similarity between Japan and Colombia. Although the weathering profile in Japan shows the distribution of chlorite, illite and vermiculite in zones from weathered granite B to "masa" B, that in Colombia shows their distribution in zones one stage earlier, i.e., weathered granite A and their disappearance one stage earlier, i.e., "masa" A. Kaolin-minerals, though appearing in zones from "masa" A in Japan, also appears one stage earlier in Colombia, i.e., in weathered granite B. This simply means lags of one stage in appearance and disappearance, and represents considerable similarity between Japan and Colombia.

K-feldspar is contained in all the weathering zones and seems hardly altered even in "masa" in Japan but alteration occurs from weathered granite A with complete disappearance in "masa" B in Colombia. Initial appearance of gibbsite occurs in "masa" B in Japan but from weathered granite A in Colombia. Furthermore, biotite rapidly decreases in weathered granite A in Colombia. These may represent dissimilarity in weathering between Japan and Colombia.

CHEMICAL COMPOSITION OF WEATHERING ZONES

Chemical analysis was carried out by X-ray fluorescence spectrometer (XRF) on the same kinds of samples used for mineralogical analysis. Table 1 lists the results of chemical analysis. The transfer of chemical components due to weathering was determined on the basis of the chemical composition shown in Table 1, assuming that Al_2O_3 was invariable. The results of calculation are shown in Fig. 5, in which the horizontal axis represents the mean depth from the surface in the weathering profile (KIMIYA, 1975) and the vertical axis represents the weight percentages of respective chemical components in each weathering zone. XRF due to its restriction in mechanism fails to permit separate measurement of Fe_2O_3 and FeO and also measure-

Table 1 Results of chemical analysis

Weathering zone Chemical components	Granite A (zone I)	Granite B (zone II)	Weathered granite A (zone III)	Weathered granite B (zone IV)	"Masa" A (zone V)	"Masa" B (zone VI)	Red "masa" (zone VII)	"Shimofuri" clay (zone VIII)
wt %								
SiO ₂	68.71	69.02	63.82	62.89	57.41	50.20	58.17	51.96
TiO ₂	0.34	0.33	0.34	0.39	0.47	1.37	0.58	0.92
Al ₂ O ₃	16.75	17.11	18.67	20.36	23.48	27.76	26.34	29.06
total Fe	3.21	2.95	3.10	3.74	5.54	12.42	4.32	7.73
MnO	0.07	0.09	0.06	0.09	0.08	0.06	0.00	0.00
MgO	1.27	1.00	1.13	1.18	1.24	0.04	0.26	0.24
CaO	3.75	1.76	1.21	0.87	0.27	0.10	0.10	0.09
Na ₂ O	3.70	2.87	1.60	0.98	0.43	0.31	0.14	0.29
K ₂ O	1.56	1.70	1.66	1.77	1.65	0.10	0.16	0.08
P ₂ O ₅	0.16	0.19	0.15	0.17	0.22	0.19	0.09	0.11
total	99.57	97.02	91.74	92.44	90.80	93.05	90.14	90.48

Fig. 5 Transfer of chemical components in weathering zones.

ment of H₂O content. The method of MATSUMOTO and URABE (1980) was used for XRF analysis and correction.

As shown in Fig. 5, SiO₂, CaO, Na₂O, K₂O, MgO, MnO, and P₂O₅ show the trend to decrease, as weathering proceeded. However, the decreasing behaviors which specifically differ individually can be divided into the following 4 patterns.

CaO and Na₂O draw concave-shaped curves, and though reduction is rapid in the initial stage of weathering, they remain almost unchanged in the late period of weathering. The absence of the change in the late period is due to heavy reduction of the CaO content below 0.3% in "masa" A, allowing no further subsequent decrease. MgO and K₂O decrease very slightly from weathered granite A to "masa" A but assume sudden decrease, when "masa" A is shifted to "masa" B. The MgO and K₂O contents which were already reduced to the bottom of 0.1–0.2% remain unchanged thereafter, because no more decrease is allowed to take place. P₂O₅ and MnO gradually decrease, although rather variably, from weathered granite A to "masa" B but rapidly decrease, when the change from "masa" B to red "masa" occurs. They maintain the same level thereafter. SiO₂ decreases in a convex curve until "masa" B, after when it resumes an increase, resulting in a re-decrease in "shimofuri" clay.

On the other hand, TiO₂ and total Fe show the trend of some increase with the progression of weathering. However, this trend is considerably disturbed in the late stage of weathering. The increase quickens suddenly when the change from "masa" A to "masa" B takes place, which is followed by abrupt decrease in red "masa". The increase returns again, when red "masa" is changed to "shimofuri" clay.

Comparison of these results with the data obtained in the similar study (KIMIYA, 1975) on the weather-

ing crust of granitic rocks in Japan shows the following. The study in Japan, however, covered only zones I-VI and accordingly the data in zones VII and VIII are not available.

The transfer tendency of SiO_2 resembles closely between Japan and Colombia. The transfer of CaO and Na_2O shows the tendency of decrease in a convex-shaped curve in the weathering crust in Japan but in a concave-shaped curve in Colombia. The transfer of MgO and K_2O shows almost no change in the weathering crust in Japan but a tendency of rapid decrease in Colombia in "masa" B. Total Fe rapidly increases in the weathering crust in Colombia in "masa" B but such a tendency is non-existent in Japan. TiO_2 , P_2O_5 and MnO do not allow comparison, because of very low contents.

CORRELATION AMONG PHYSICAL, CHEMICAL AND MINERALOGICAL CHANGES

Although "masa" A (zone V) contained 25% pebble-size grains, the pebble-size grain content is reduced to almost nil in "masa" B (zone VI). This conforms to the time of disappearance of the primary minerals such as K-feldspar, plagioclase and biotite. The clay-size grains that were absent in "masa" B increase to approximately 20% in red "masa" (zone VII). This conforms with the time for the secondary minerals such as chlorite, illite, vermiculite and gibbsite to disappear and transform into kaolinite alone. The above indicates close correlation between the physical changes and mineralogical changes.

On the other hand, following correlation was obtained between the chemical changes and mineralogical changes. The decrease in CaO and Na_2O with advance of weathering, especially seriously in "masa" A, well corresponds with the start of the decrease in plagioclase in weathered granite B (zone II) which becomes meager in "masa" A and completely disappears in "masa" B. The rapid decrease in K_2O when the change from "masa" A to "masa" B occurs well corresponds with the presence of K-feldspar until "masa" A and disappearance in "masa" B. The rapid decrease in MgO when "masa" A is changed to "masa" B well corresponds with the presence of vermiculite transformed from biotite in "masa" A and disappearance in "masa" B. SiO_2 decreases with the progression of weathering but resumes an increase in red "masa". This also well corresponds with the presence of gibbsite until "masa" B which transforms to kaolinite in red "masa". The above indicates that the chemical and mineralogical changes are very closely correlated.

Although literatures have shown that the progression of weathering induces reduction of SiO_2 with the result of final formation of gibbsite, the new finding obtained in the present study shows that further progression of weathering to red "masa" or "shimofuri" clay induces, on the contrary, infusion of SiO_2 with the consequence of kaolinite formation from gibbsite.

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要 旨

コロンビア国アンティオキア花こう岩体の風化殻分帯については、すでに報告したように 11 に分帯されているが、今回はそのうちのレスおよび土壌を除いた 8 帯を研究対象とした。

粒度分析の結果、マサ A (zone V) からマサ B (zone VI) への変化は、礫から砂への変化が特徴であり、マサ B から赤色マサ (zone VII) への変化は、シルトから粘土への変化が特徴である。また、赤色マサからしもふり粘土 (zone VIII) への変化はシルトから粘土への変化はあまり見られず、砂からシルトへの変化が進行する。

鉱物組成の変化を X 線回析法により調べた結果、石英は全く風化しないが、日本においてはほとんど変化しないカリ長石は、風化花こう岩 A (zone III) より変質が始

まり、マサBで消滅してしまう。斜長石、黒雲母も風化の初期段階で消滅する。これに対し、中間生成物として緑泥石、イライト、ハロサイト、ギブサイトが見られ、最終段階でカオリナイトが現われる。日本の花こう岩の風化においては、ギブサイトが最終産物であると考えられてきたが、ここではカオリナイトであった。このことは、XRF による化学分析の結果、 SiO_2 は風化の進行に伴い減少する傾向を示すが、赤色マサになるときに逆に増加することとよく対応する。すなわち、赤色マサになると SiO_2 が濃集し、それに伴いギブサイトがカオリナ

イトに変化すると考えられる。

化学組成の変化を日本の風化殻での結果と比較すると、 CaO 、 Na_2O 、 K_2O 、 SiO_2 などが風化の進行に伴い減少する傾向にあるのは同じであるが、その時期はコロンビアの方がかなり早い。すなわち、 CaO 、 Na_2O は日本においては風化の中期～後期になってから減少するが、コロンビアでは風化の初期に著しく減少する。また、 K_2O 、 MgO は日本ではわずかに減少するにすぎないが、コロンビアではマサBになると急減する。

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