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Weathering Process in Foliated Rocks

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Abstract -Three granitic mylonite samples weathered different degrees were investigated by an image analyzing technique and TEM microscopy. Alteration of hornblende were completed in early stage of weathering prior to alteration of plagioclase. Weathering is preferably promoted at twin boundaries and portions with high dislocation density.

I. Introduction

In weathering process, rock-forming minerals dissolve into solution and hydrous aluminosilicate minerals precipitate [1,2], resulting in weakening of their strength and/or cohesion. This process is closely related with occurrence of natural disasters such as landslide and slope failure. The durability of rock forming minerals against weathering and their spacial distribution pattern determine mechanical behavior of rocks under the earth's surface environment. Along large-scale fault zones and in regional metamorphic belts, foliation, which is defined by planer distribution and compositional banding of minerals, develops in a rock. It has been well known that foliation plane becomes mechanically weaker during weathering, and could operate as a slip plane of mass movement. Therefore, evaluation of weathering process of individual minerals is fundamental but essential for study of prevention of natural disasters.

In this study, three granitic mylonite samples weathered different degrees were analyzed by a X-ray diffractmeter (XRD), an optical (OM) and transmission electron microscope (TEM). Weathering process of each rock-forming minerals was evaluated by an image analyzing technique. Effects of pre-formed micorostructures on weathering manner were also focused in this study.

II. Sample description

Cretaceous Ryoke Granotoids are exposed in Southern margin of Osaka plane, SW Japan. The E-W trending and steeply dipped ductile shear zones widely occur within the Granotoids in Kishiwada district. One of representative rock type around this area is the Mizuma granodiorite: coarse-grained schistose granodiorite consisting of Plagioclase, K-feldspar, quartz, hornblende and biotite [3]. Three differently weathered samples, A: apparently fresh, B: easily fragmented and C: unsolidified (Masa-soil) were collected from an outcrop of this granodiolite.

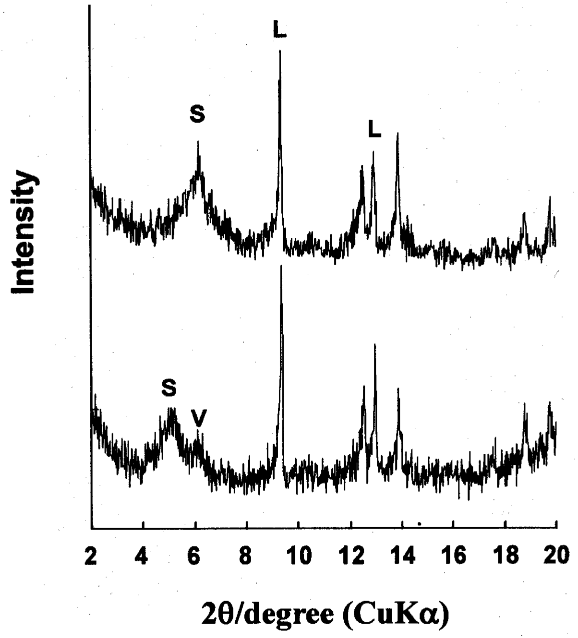

Fig. 1 XRD profiles of whole rock (Sample C) both for air-dried(upper profile) and Ethylene Glycol solvated (lower profile) samples. L: laumontite, S: smectite, V: vermiculate.

In the sample, quartz grains are highly deformed and flattened parallel to the foliation plane. Feldspars occupy large volume, more than 50 percent of the rocks. They deformed in both brittle and ductile manners. Hornblende and biotite exhibit tabular and platy shapes, respectively. They tend to array parallel to the foliation and connect each other forming penetrative layers (mica-rich layers).

XRD analyses of whole rock (Sample C) both for air-dried and Ethylene Glycol solvated samples were performed for clay mineral identification. XRD profiles indicate that laumontite, smectite, vermiculate, and chlorite occurred during weathering process (Fig. 1). Biotite and hornblende grains are altered by vermiculite and chrolite. Alternation of hornblende proceeds along cleavage from surface to interior. Secondary minerals widely distribute in feldspar grains, scattered as small patches in whole grains or occupying along microcracks and cleavages. Quartz grains look fresh and do not have influence of weathering even in sample C. With weathering more significant, volume fraction of secondary minerals looks increase.

III. Image analysis of hornblende and feldspar grains

A. Method

An image analyzing technique for estimation of degree of alteration was applied on hornblende and feldspar grains in the differently weathered three samples. In this analysis, area fractions of altered portions in grains were measured on the OM-photoimages. Firstly brightness range of the unaltered portion was determined in the image with a threshold defined as the brightness value at foots of the peak in a brightness histogram for the unaltered homogeneous area (Fig. 2 left histogram). Next, the areas which have the brightness out of the range between two thresholds were measured, regarding them as altered portions (Fig. 2 right histogram).

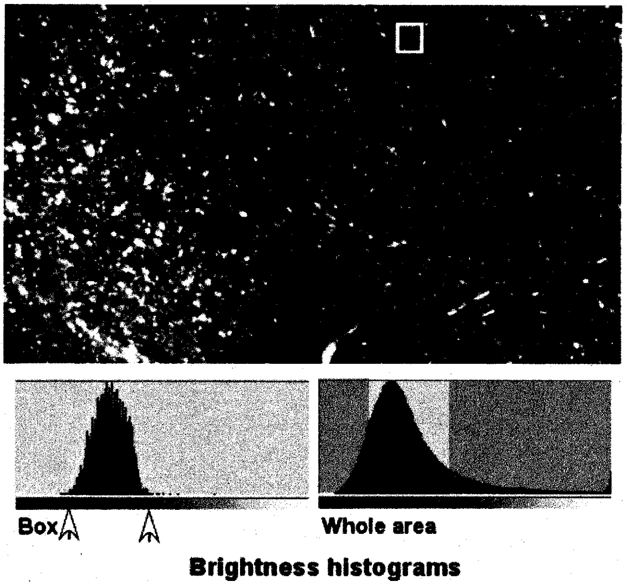

Fig. 2 A phtomicrogrph of weathered feldspar in sample B, and its brightness histograms (left: inside of white box, right: whole area). Thresholds for division of altered and unaltered are defined as the brightness value at foots of the peak in a brightness histogram (left hand) for the unaltered homogeneous area (inside of the white box in this case), which is indicated by arrows

B. Results

The alteration of biotite, hornblende and plagioclase by secondary minerals are intense in order of C, B, and A (Fig . 3). The area fractions of altered portions in hornblende are ranging from 40 to 60, and from 70 to 80 percent in sample A and B, respectively. For sample C, it seems that hornblende has been almost diminished during weathering process. The area fraction of altered portions in plagioclases are ranging from 15 to 60, from 50 to 95 and from 45 to approximately 100 percents for sample A, B and C, respectively. The degree of alteration is scattered widely in plagioclase samples.

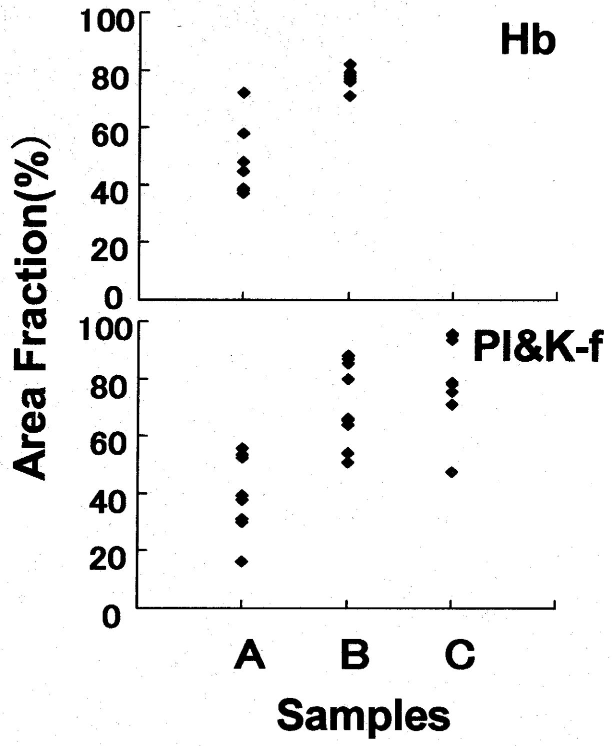

Fig. 3 Area fractions of altered portion in hornblende (upper box) and feldspar (both K-feldspar and plagioclase; lower box) grains. Each point corresponds to area fraction of one grain.

IV. TEM observation

In order to identify secondary minerals and relation of their precipitation sites with microstrucutres developed in a grain such as twin boundaries and dislocations, a plagioclase porphiroclast in sample C was observed by TEM (JEOL JEM2000EX) at 160kV accelerate voltage.

Albite twin boundaries are coherent, occurred as sharp strait boundaries under TEM (Fig. 4). Dislocations and subgrain boundaries heterogeneously distribute, highly tangled in some parts and absent in another large areas (Fig. 4a). Secondary minerals look to grow at the area with a high dislocation density (Fig. 4a) and in the dissolution windows whose shapes are primarily controlled by albite twin boundaries (Fig. 4b). Most of secondary minerals are fibrous

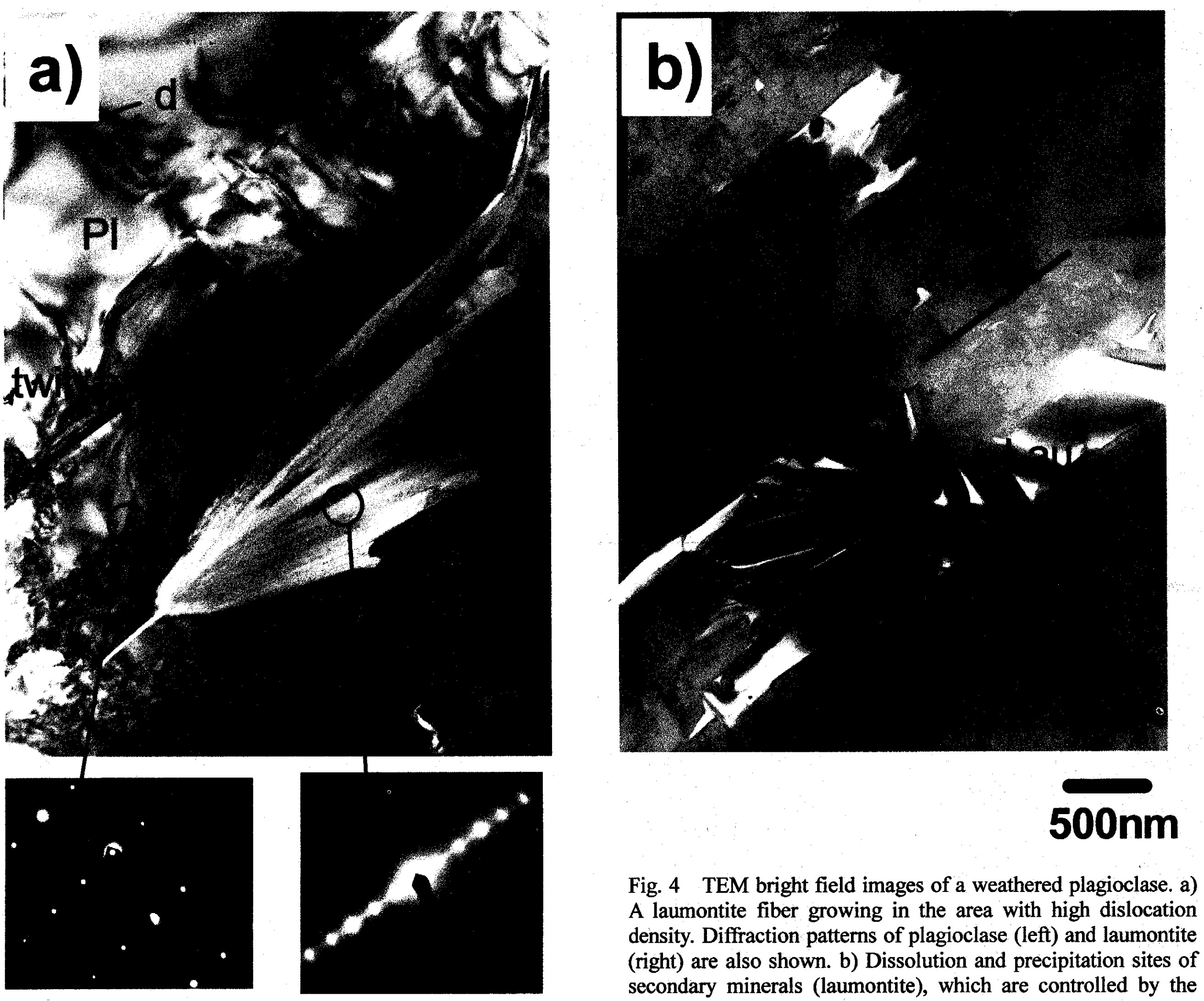

Fig. 4 TEM bright field images of a weathered plagioclase. a) A laumontite fiber growing in the area with high dislocation density. Diffraction patterns of plagioclase (left) and laumontite (right) are also shown. b) Dissolution and precipitation sites of secondary minerals (laumontite), which are controlled by the orientation of albite twin boundaries. Pl: plagioclase, Lau: laumontite, twin b: albite twin boundary, d: dislocation.

form. Orientations of these fibers are not controlled by crystallographic orientation of host plagioclase, but seem to depend on orientations of walls enclosing free spaces. The *d*-spacing of fibrous crystals was obtained by diffraction patterns as d=10.0Å in normal to the fiber, close to that of (110) plane of laumontite.

V. Discussion and Summary

TEM microscopy revealed that the sites of dissolution and precipitation reaction are strongly controlled by microstructures developed in minerals. Particularly it is found that weathering is preferably promoted at twin boundaries and portions with high dislocation density. This may be driven by the excess surface and strain energies generated around these structures. Similar phenomena have been reported in the study on weathering of K-feldspars, where exsolution lamella is primarily important site for dissolution [1].

Alteration of hornblende in the present sample completes in early stage of weathering prior to weathering of plagioclase. Weathering of platy and tabular minerals in foliated rocks is especially important on the viewpoint of prevention of the landslide disaster. The coherency of the mica rich layers of foliated rocks would be loosed with weathering of these minerals resulting in mechanical anisotoropy of the rocks more intense.

The results of the image analyzing technique presented in this study show positive correlation with weathering degree defined by the criteria established on field basis. Therefore this could be useful for evaluation of weathering degree of rocks. However, there are some uncertainties in the criteria for division of altered and unaltered portions in this color-contrast based method. Secondary minerals with same brightness ranges as host minerals cannot be distinguished. Noises caused by reflections around cleavages and fluid inclusions are hardly excluded. Weathering process involves with dissolution of host and precipitation of secondary minerals, which is associated with removal of some chemical components from rocks. Therefore, the analysis on the basis of chemical composition is required for establishment of more reliable estimation of weathering process.

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