CHEMICAL WEATHERING OF BIOTITE-PLAGIOCLASE GNEISS

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ABSTRACT

The weathering of biotite-plagioclase gneiss was studied in a warm humid climate under good drainage conditions, in De Kalb County, Georgia. A series of samples ranging from completely weathered to fresh rock were studied. The degree of weathering was determined by bulk specific gravity and abrasion pH of samples in various stages of decomposition. Quantitative determination of clay minerals was done by DTA. Results show that the stable products of andesine weathering are kaolinite and endellite, and that biotite weathers to a mixture of amesite and kaolinite. There is no volume change in the gneiss as it weathers from fresh rock with a bulk specific gravity of 2.78 to a completely friable saprolite with a bulk specific gravity of 1.4. The weathering is accompanied by an increase in kaolin minerals from zero to about 35 per cent. The process involves the solution of plagioclase and biotite with approximately simultaneous crystallization of clay minerals and hydrated oxides of aluminum and iron.

INTRODUCTION

SIXTY-SIX saprolite and rock samples were collected from excavations in various parts of central De Kalb County, Georgia. The U.S. Geological Survey, Decatur Quadrangle, 1954, shows the local relief to be about 100 ft and the average elevation about 950 ft above sea level.

The climate is warm and humid, slightly modified by elevation. Annual average precipitation is 47.58 in. but variations are considerable. The

TABLE 1.—MODAL ANALYSES OF BIOTITE-PLAGIOCLASE GNEISS

							Average
Quartz	37	28	28	26	22	22	27
Plagioclase*	48	28	33	35	29	36	35
Biotite	10	34	36	36	33	39	32
Muscovite	5	6	1	tr	12	2	4
Accessories†	tr	4	2	3	3	tr	2

*Plagioclase composition varies from An_{33} to An_{35}.

†Accessories include magnetite, pyrite, pyrrhotite, garnet, sillimanite, epidote, and incipient weathering products.

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July temperature averages 78.5°F and the January temperature averages 44.0°F (Mindling, 1941).

The outcrops are composed mainly of biotite-plagioclase gneiss with minor intercalations of amphibolite and biotite schist. Samples studied were selected megascopically from the gneiss layers. The only variation in the gneiss is the presence or absence of andesine porphyroblasts which do not appear to affect the total mineralogic composition. Microscopically the gneiss shows a strong foliation and a ground mass grain size ranging from 0.1 to 0.5 mm. Porphyroblasts of sodic andesine range in size from 2 to 20 mm. Modal analyses of six of the freshest samples are given in Table 1.

Detailed sampling was done in excavations at the intersection of N. Druid Hills Rd. and the Seaboard Railroad. A complete sequence from weathered to fresh rock was exposed here. Samples from other less complete exposures were compared to this complete or "standard section". The section occurred in a small hill with an area of about 6 acres, which rose roughly 50 ft above the surrounding area. The depth of soil and saprolite overlying fresh rock varied from roughly 30 to 40 ft. The center of the hill was occupied by hard rock. Weathering increased in degree both laterally and vertically. The hill is underlain by a complex open anticlinal structure whose gently plunging fold axis strikes at roughly right angles to the long axis of the hill. Three sets of vertical joints are present plus a well-developed foliation. These structures permit the access and control the distribution of meteoric water. Field studies show that weathering proceeds down foliation planes and to a lesser extent along joints. Patches of rock left unweathered by reason of composition or texture are invariably elongated parallel to the foliation. Field observations show that all samples came from well-drained sections.

PROCEDURES

Sampling was restricted to the saprolite zone, i.e. from fresh rock to the point where original rock texture is no longer discernable. This latter point coincides approximately with the base of the B horizon which is characterized by a heavy, virtually structureless red clay. A total of eight different localities are represented in the 66 samples studied.

Mineral identification is based primarily on over 150 differential thermal analyses. Petrographic techniques such as oil immersion and thin sections were used in a supporting role. Confirmation of identifications of selected samples was made by X-ray diffraction. Quantitative DTA estimations were made by modifying previously described techniques (Grant, 1963, p.66) for the biotite-plagioclase gneiss. Accuracy of data is difficult to define but the overall consistency of results indicates that it is satisfactory.

Qualitative microchemical analysis was used in the biotite study.

Standard qualitative tests determined the presence or absence of ions in samples of known degree of weathering, as measured by density.

Separation of biotite from residuum was accomplished by an electro-magnetic separator followed by washing to remove the superficial clay. A second separation with a permanent magnet to remove magnetite was necessary on some samples. The density of milligram quantities of fresh and weathered biotite was determined on the Berman torsion balance. Abrasion pH was determined by the method of Stevens and Carron (1948) using a Beckman Model G pH meter.

Bulk specific gravity is an index of the degree of weathering of many rocks. Its determination has been described (Grant, 1963, p.66).

Abrasion pH of weathered rock was determined by using a modification of the technique of Stevens and Carron (1948) described by Grant (1963, p.67). Abrasion pH is also a measure of the degree of rock weathering.

RESULTS

The bulk specific gravity of weathered rock samples plotted against their kaolin content, as determined by DTA, results in the curve shown in Fig. 1. This is interpreted as a reaction curve with decreasing bulk
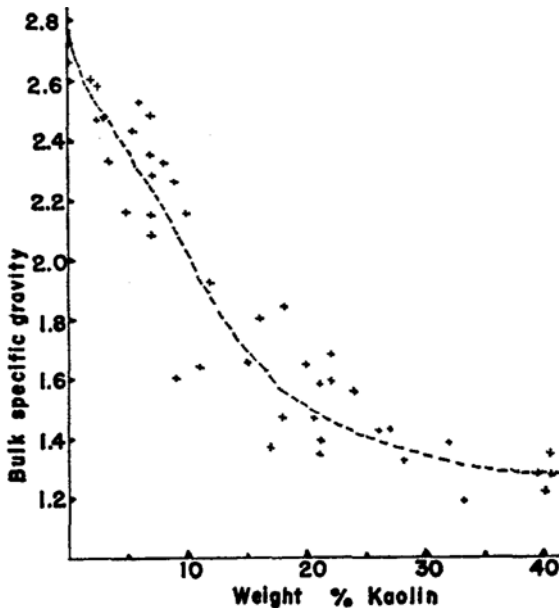

FIGURE 1.—The relation between bulk specific gravity of saprolite and the amount of kaolin minerals as determined by thermal analysis.

specific gravity defining the loss in mass of the reactants, biotite and plagioclase, and an increase in the product, kaolin, as weathering progresses. The soluble constituents remain unaccounted for. A typical DTA curve of raw saprolite is shown in Fig. 6B.

The relation between abrasion pH and weight per cent kaolin in saprolite is shown in Fig. 2. The curve shows that cations, mainly sodium, potassium and calcium, are being removed in solution, as the amount of kaolin in-
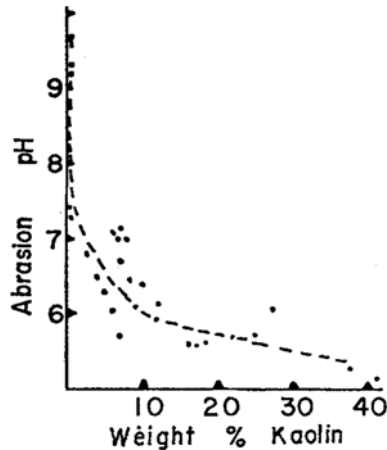

FIGURE 2.—The relation between abrasion pH of rock slurries and their kaolin content as determined by DTA.

creases. Both curves support the field observation that weathering below the B horizon is a process of solution and crystallization of new minerals without appreciable volume change in the original rock.

Microscopic studies show that plagioclase is first attacked along cracks and cleavages, working from the surface of the grain inward. The first weathering products are gibbsite and probably allophane. Identification of allophane is based on its association with plagioclase, isotropic optical behavior and a refractive index of 1.473 ± 0.003. Endothermic DTA peaks at 320°C are attributed to gibbsite, which is associated with partially weathered feldspar. Ground mass feldspar when completely weathered yields mainly kaolinite (Fig. 6E). Andesine porphyroblasts, because of their large size, react more slowly than the ground mass feldspar. This is shown by the presence of only porphyroblastic feldspar fragments in saprolites with bulk specific gravities between 1.5 and 1.6. The clay derived from porphyroblastic feldspar is endellite, Fig. 6F. From this it seems probable that the early products of feldspar weathering are gibbsite and allophane, neither of which is stable. Kaolinite and endellite are the stable end products.

Optical studies of weathered biotite show a decrease in refractive index,

an increase in 2V, and a color change in transmitted, plane polarized light, observed normal to 001. The color changes are from dark greenish brown in fresh biotite, through red brown and ultimately to progressively paler yellow browns as the amount of weathering increases. Megascopically the fresh flakes are black and the more weathered ones have a brassy sub-metallic luster. Microscopic clumps of limonite are scattered sparsely on the cleavage planes of weathered biotite.

Differential thermal analyses of weathered biotite show two, Fig. 6C, and sometimes three, Fig. 6A, endothermic peaks which occur at approximately 320°, 580° and 620°C. The 320°C peak is attributed to gibbsite. It persists after samples are boiled in HCl, which would not be the case if goethite or lepidocrocite caused the peak. The 580°C endothermic peak and a small exothermic peak at roughly 920°C is attributed to kaolinite. The 620°C endothermic peak is attributed to amesite. This mineral is soluble in boiling 1 : 1 HCl as is shown by the complete disappearance of the 620°C endothermic peak, Fig. 6D. The presence of kaolinite is confirmed by X-ray diffraction, but amesite is not. The d spacings (Brindley, Oughton and Youell, 1951) for amesite are so close to those for kaolinite that it is possible that the amesite is completely masked by the more abundant kaolinite.

The relation between the density of weathered biotite and the bulk

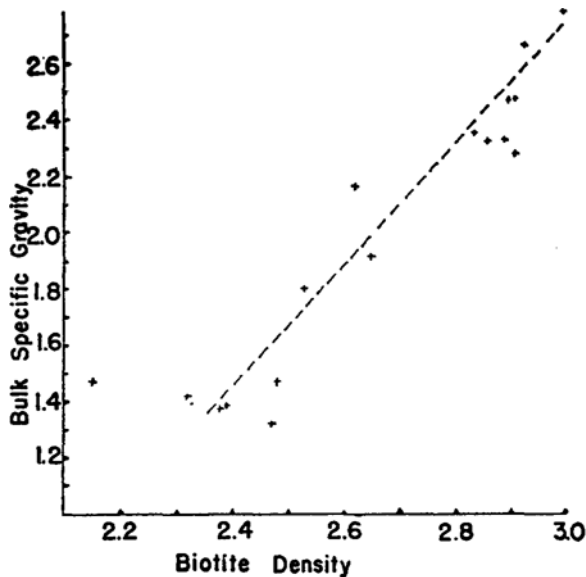FIGURE 3.—The approximately linear relation between the degree of rock weathering and the degree of biotite weathering as indicated by biotite density and bulk specific gravity of saprolite.
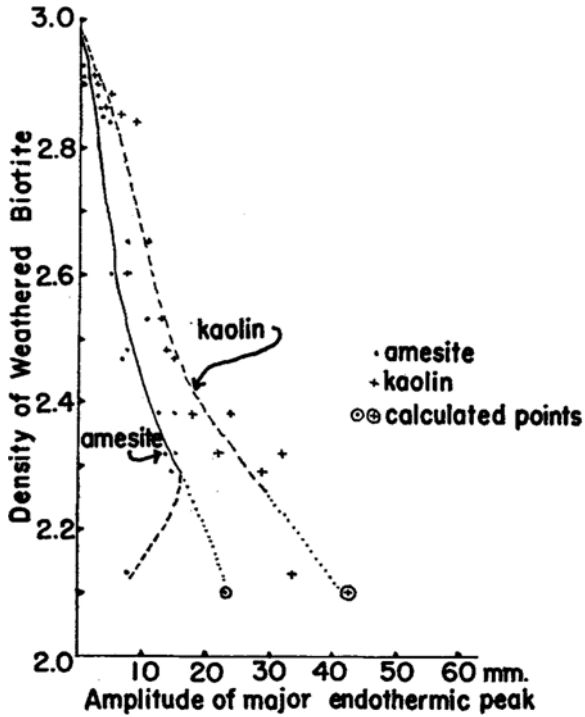
FIGURE 4.—The relation between the degree of weathering as measured by density of the biotite and the amount of amesite and kaolinite.
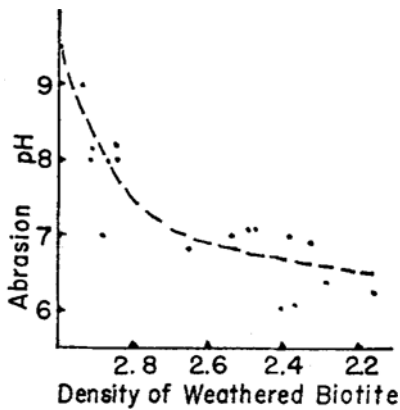

FIGURE 5.—The variation of abrasion pH with density in biotite flakes of various degrees of weathering.

specific gravity of weathered rock is shown in Fig. 3. It indicates that the trends in biotite weathering are in general the same as the whole rock.

The relation between the density of weathered biotite and the amplitudes of the 580°C and the 620°C endothermic peaks representing kaolinite and amesite respectively is shown in Fig. 4. The curve for kaolinite shows approximately twice the amplitude of the amesite curve. This is interpreted to mean that there is twice as much kaolinite as amesite, which seems reasonable since the two minerals are structurally similar. The curves also show that the formation of kaolinite and amesite continue in a consistant manner down to a biotite density of 2.3. Below this density the amount of amesite declines while the kaolinite continues to increase. This suggests that the amesite may ultimately alter to kaolinite. Data on this latter
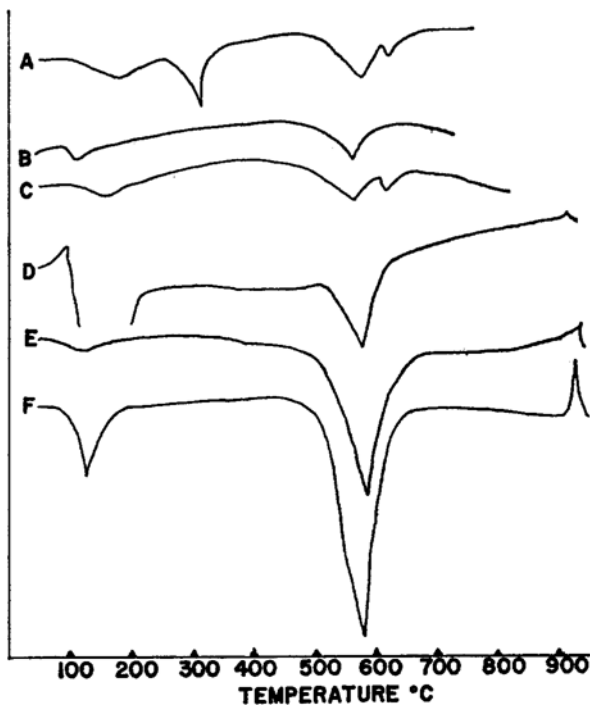
FIGURE 6.—Thermograms of biotite-plagioclase gneiss saprolite and derived fractions.

A—Weathered biotite showing gibbsite, kaolinite, and amesite endotherms.
B—Raw biotite-plagioclase gneiss saprolite.
C—Weathered biotite extracted from B, shows kaolinite and amesite endotherm.
D—Biotite from C leached with 1 : 1 HCl shows only kaolinite endotherm.
E—Clay fraction extracted from saprolite, composed mainly of kaolinite derived from ground mass feldspar.
F—Endellite derived from plagioclase porphyroblasts.

point are sparse. The two calculated points on Fig. 4 are based on the reaction given below going to completion. They fit the curves but indicate that the reaction does not go to completion under natural conditions. This is supported by other data.

The variation of abrasion pH with density of weathered biotite is shown in Fig. 5. The pH declines rapidly down to a density of 2.6. Microchemical qualitative tests for potassium indicate that the decline in pH is due to the leaching of this element.

The representative thermal curves cited are collected in Fig. 6.

The evidence available suggests the following reactions are possible.

$$4K_2 (Mg\ Fe_2Al_2)\ Al_2Si_6O_{20} (OH)_4 + 4H_2O + 10CO_2 \longrightarrow 2Al_4Si_4O_{10} (OH)_8$$
$$\text{biotite} \qquad\qquad\qquad\qquad\qquad \text{kaolinite}$$
$$+ Mg_4Al_2(Al_2Si_2O_{10}) (OH)_8 + 14SiO_2 + 4KAlO_2 + 8FeCO_3 + 2K_2CO_3;$$
$$\text{amesite}$$
$$4KAlO_2 + 4H_2O + 2H_2CO_3 \longrightarrow 4Al(OH)_3 + 2K_2CO_3;$$
$$\text{gibbsite}$$
$$8FeCO_3 + 8H_2CO_3 \longrightarrow 8Fe^{++}(HCO_3)_2 + 2O_2 + 20H_2O \longrightarrow$$
$$8Fe^{+++}(OH)_3 + 16H_2CO_3.$$
$$\text{limonite}$$

Much available evidence suggests that weathering takes place by ordinary stoichiometric reactions. Calculations were made determining the amount of kaolin to be obtained by complete weathering of the average rock as given in Table 1. The theoretical percentage of kaolin is 34 per cent. The average kaolin content measured in the ten most weathered specimens is 33 per cent.

CONCLUSIONS

Under conditions of good drainage and a warm climate the weathering of biotite-plagioclase gneiss proceeds as follows:
1. The first weathering products of plagioclase are gibbsite and probably allophane, both of which are unstable. The stable end products are kaolin minerals.
2. Biotite weathers to a mixture of kaolinite and amesite.
3. Between fresh rock and the base of the B horizon there is no volume change in the gneiss.
4. Weathering is a process of solution and crystallization.

These results differ from those of Walker (1949) who studied biotite decomposition in the soil and found that biotite altered to vermiculite.

ACKNOWLEDGMENTS

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