MINERALOGICAL AND CHEMICAL CHANGES DURING WEATHERING OF ACID AND BASIC ROCKS IN UGANDA

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Mineralogical and chemical changes that accompany early stages of weathering are described from a tropical climate in Uganda. The weathering product of a granitic gneiss and an amphibolite was analysed mineralogically by X-ray diffraction and chemically by X-ray fluorescence. While the amphibolite weathers into essentially kaolinite and iron oxides the weathering product of the granitic gneiss includes quartz, illite, mixed layered minerals and smectite in addition to kaolinite. It is concluded that the stability of clay minerals formed during weathering is not only a function of precipitation but is also dependent on the composition of the parent rock.

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The object of the present paper is to describe the mineralogical and geochemical changes that occur during the initial stages of the weathering of crystalline rocks of basic and granitic composition in a tropical climate. Two sections not far from Kampala, Uganda (Fig. 1) were chosen:

Section 1: Granitic Precambrian gneiss. Mutoga Quarry 15 km north of Kampala (Bombo road).
Section 2: Amphibolite of the Uganda-Toro system (Precambrian) exposed in road section (Kampala-Nairobi road) east of Jinja.

The field work was carried out while the author was working at Makerere University (1969–1971) and the laboratory analyses were done at Institutt for geologi, Universitetet i Oslo. The samples were analysed by X-ray diffraction techniques following standard procedures described by Carroll (1970). X-ray fluorescence analyses were carried out by using fused lithium tetraborate glass beads and international rock standards.

Weathering of granitic gneiss

Samples were collected from the face of the Mutoga Quarry, which is located near the bottom of Mutoga Hill. This is an inselberg consisting of Precambrian basement rocks, mainly granitic gneisses. In the quarry apparently fresh granite gneiss is exposed (sample M1). The unweathered gneiss is intersected by weathered zones following joints and fractures. Sample M2 is taken from
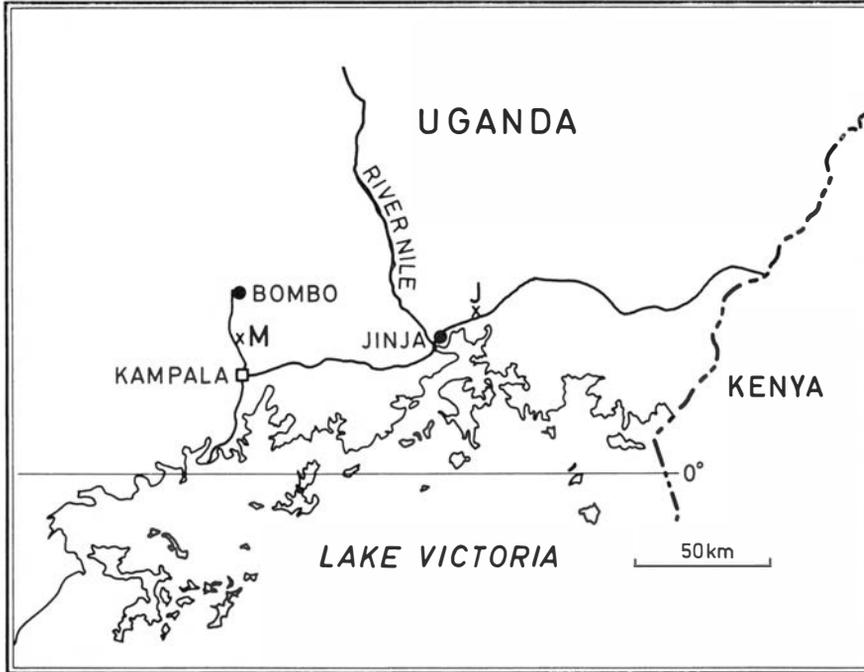
Fig. 1. Map showing the location of the section studied. M – Mutoga Quarry (granitic gneiss); J – Amphibolite east of Jinja.

a zone of initial weathering where red staining is present due to iron oxidation, mainly from biotite but where the feldspars and the whole texture are essentially unchanged. Sample M3 represents more weathered gneiss whose texture is also unchanged. Overlying the in situ weathered gneiss is a soil of weathered granitic material (sample M4). These four samples represent dif-

Table 1. Chemical analyses of weathered granitic gneisses from Mutoga Quarry, Uganda. (Samples M1–M4 represent stages of increasing weathering.)

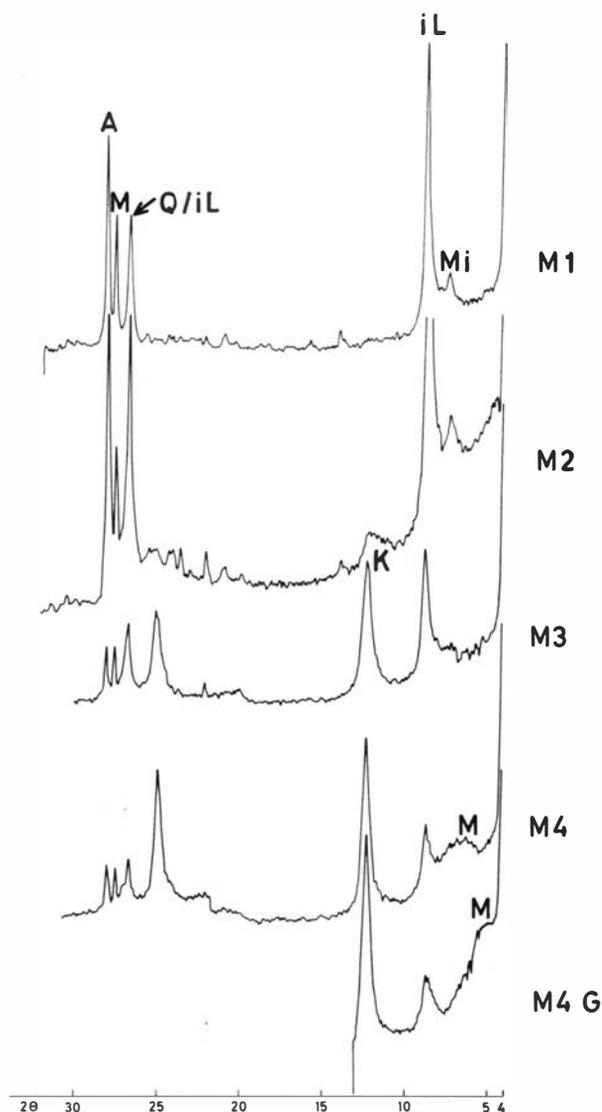|	M1	M2	M3	M4
SiO_2	64.16	65.69	68.10	64.89
TiO_2	0.62	0.60	0.46	0.64
Al_2O_3	17.37	17.66	17.59	20.34
Fe_2O_3	4.87	4.99	4.12	5.27
MnO	0.10	0.08	0.06	0.06
MgO	1.74	1.37	1.15	1.15
CaO	3.26	2.64	1.12	0.97
Na_2O	4.20	4.03	2.46	2.21
K_2O	3.33	3.32	3.78	4.30
P_2O_5	0.31	0.29	0.01	0.07
Total dry rock	99.86	100.59	98.36	99.79
Loss on ignition	1.43	1.27	2.61	4.13

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Fig. 2. X-ray diffraction diagram of samples from the granitic gneiss at Mutoga Quarry 15 km north of Kampala. Apparently fresh granitic gneiss containing quartz (Q), albite (A), microcline (M), illite (iL) and small amounts of mixed-layered minerals (Mi). Samples M2–M4 represent stages of increasing weathering and the diagram shows how kaolinite/halloysite is increased as feldspar is destroyed. M4G shows that sample M4 contains expandable montmorillonite.

ferent stages in weathering. X-ray diffraction diagrams (Fig. 2) of these 4 samples give a semi-quantitative picture of the mineralogical composition.

The gneiss (M1) consists dominantly of quartz, feldspar (albite and micro-cline) and biotite. The fact that the mica is mainly trioctahedral is also indi-cated by a very weak 5Å (002) reflection (Grim 1968). A 12Å peak (M1) indicates the presence of a regularly stratified mixed layered mineral, prob-
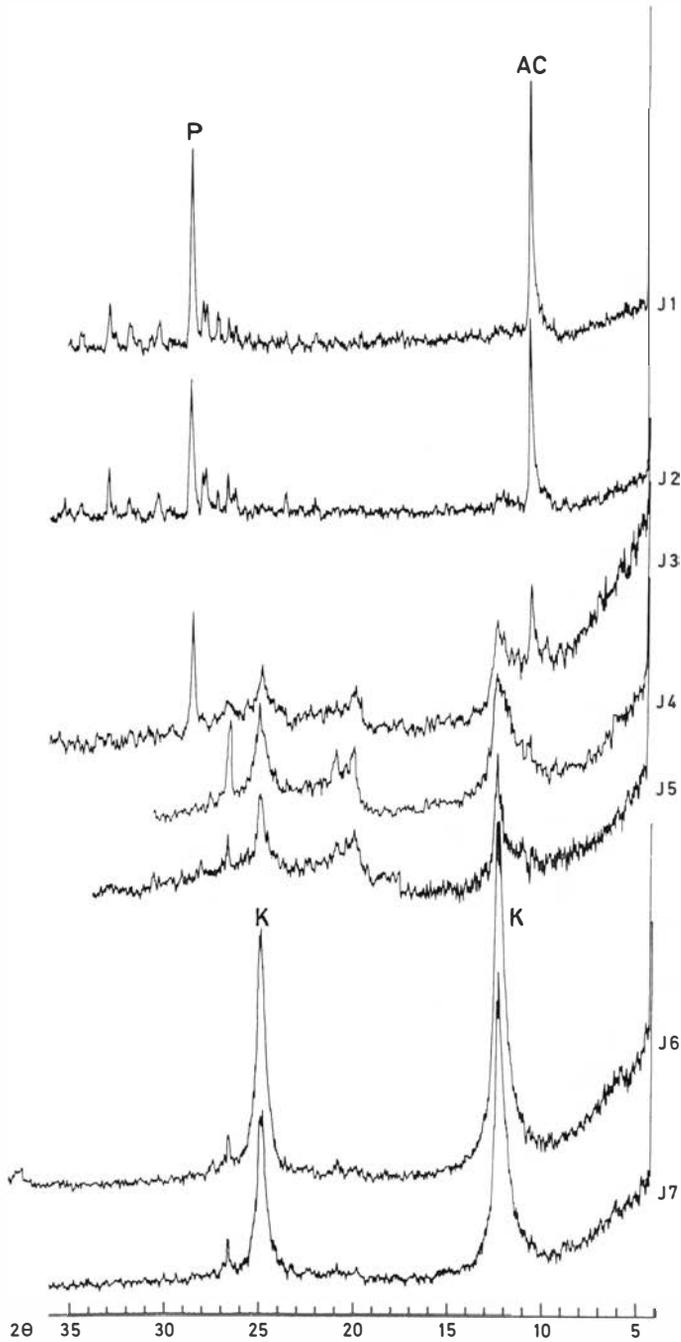
Fig. 3. X-ray diffraction diagram of samples from amphibolite from the Kampala-Nairobi road east of Jinja. The unweathered amphibolite (J1) consists mainly of plagio-clase (P) and actinolite (AC). These minerals are with increasing weathering altered to kaolinite (K) and iron oxides which are not recorded on the X-ray diffraction diagram.
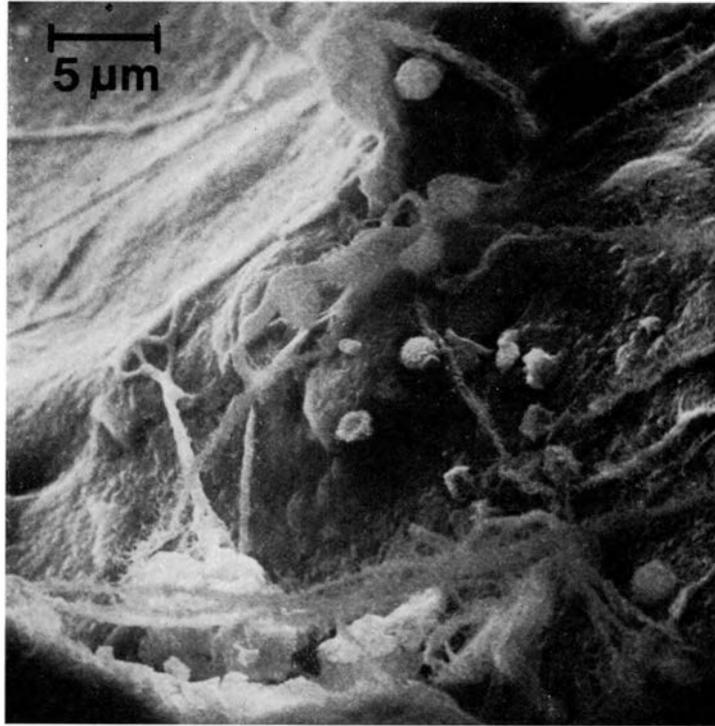
Fig. 4. Electron scanning microphotograph of fungal hyphae in weathered granite (M4). The spherical bodies are probably sporangia.

ably formed from biotite. This suggests that in the apparently unweathered gneiss, the weathering process has already started and that biotite is the first mineral to undergo alterations. In sample M2 the 12Å reflection is increased and the illite reflection becomes broader with a shoulder towards higher Å values. In this sample a small broad peak at $2\Theta = 12.5$ (7Å) indicates the presence of poorly crystalline halloysite or kaolinite, suggesting incipient feldspar kaolinization. In the next sample (M3) the 7Å reflection is strong and sharp, indicating the presence of a well-crystallized kaolinite. Both the albite and the microcline reflections are at the same time strongly reduced. The broad peak from 10.5–12Å indicates further weathering of illite and the formation of more disordered mixed-layered minerals. In sample 4 the 10Å reflection is noticeably reduced and there is a broad peak between 2Θ 5.5–7.5, (12–16Å). After glycol treatment this peak shifted towards higher values (17Å) indicating the presence of montmorillonite.

Weathering of amphibolite

In the road sections (Kampala-Nairobi road) east of Jinja, amphibolite is exposed. Six samples were collected from zones of increasing weathering in

Table 2. Chemical analyses of weathered amphibolites from the Buganda-Toro series east of Jinja, Uganda. Samples J1–J7 represent stages of increasing weathering.

	J1	J2	J3	J4	J5	J6	J7
SiO_2	52.06	50.99	47.79	46.22	46.66	45.58	44.44
TiO_2	1.36	1.44	2.37	2.58	2.56	2.77	2.46
Al_2O_3	13.77	14.24	21.88	24.46	23.74	23.66	25.80
Fe_2O_3	13.28	14.01	24.16	26.03	25.74	25.86	25.07
MnO	0.17	0.18	0.12	0.07	0.10	0.34	0.22
MgO	6.25	6.54	1.53	0.43	0.58	0.51	0.45
CaO	11.28	10.71	2.47	0.35	0.50	0.26	0.09
Na_2O	1.86	1.83	0.41	0.20	0.04	0.30	0.18
K_2O	0.22	0.05	0.05	0.05	0.24	0.24	0.16
P_2O_5	0.14	0.13	0.03	0.08	0.04	0.18	0.15
Total dry rock	100.22	100.10	100.69	100.40	99.99	99.90	99.01
Loss on ignition	1.15	1.98	10.66	11.30	11.18	12.36	10.84

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the road section. J1 is an essentially unaltered dolerite while J2 is slightly weathered (only faint red staining). Samples J3–J6 represent red weathered rocks in situ. J7 is a sample of weathered soil from the top of the section.

Thin section examination and X-ray diffraction show that the amphibolite consists dominantly of two minerals, namely, actinolite and plagioclase (Fig. 3). Only small mineralogical changes are observed in sample J2. A very small $2\Theta = 12.5$ (7A) reflection might suggest incipient crystallization of kaolinite (or halloysite). In the samples from J2 to J6 one can observe an increasing intensity and sharpness of the 7Å (001) and 3.5Å (002) reflections of kaolinite. At the same time the characteristic reflections of plagioclase and actinolite disappear. The soil formed by weathering of this amphibolite thus consists mainly of kaolinite in addition to iron oxides, which do not appear on the X-ray diagram.

It is well known that many biological processes are active in the weathering process. Plants producing carbon dioxide and humic acids will lower the pH of the pore solutions. In sample M4 fungal hyphae is visible in electron microscope (Fig. 4).

Mineral transformations during weathering

Both in the granitic gneisses and in the amphibolite, kaolinization starts (J2, M2) with a broad 7–7.5Å reflection, which is characteristic of halloysite (Carroll 1970). Samples J3–J5, in particular, display relatively strong 4.48Å reflections typical of disordered kaolinites (Grim 1968), while in samples J6 and J7 these reflections become much weaker corresponding to ordered kaolinite.

Detectable amounts of mixed layered minerals and montmorillonite (smectite) are only found in the weathered gneiss and not in the weathered amphi-

WEATHERING PROFILE

Increased weathering

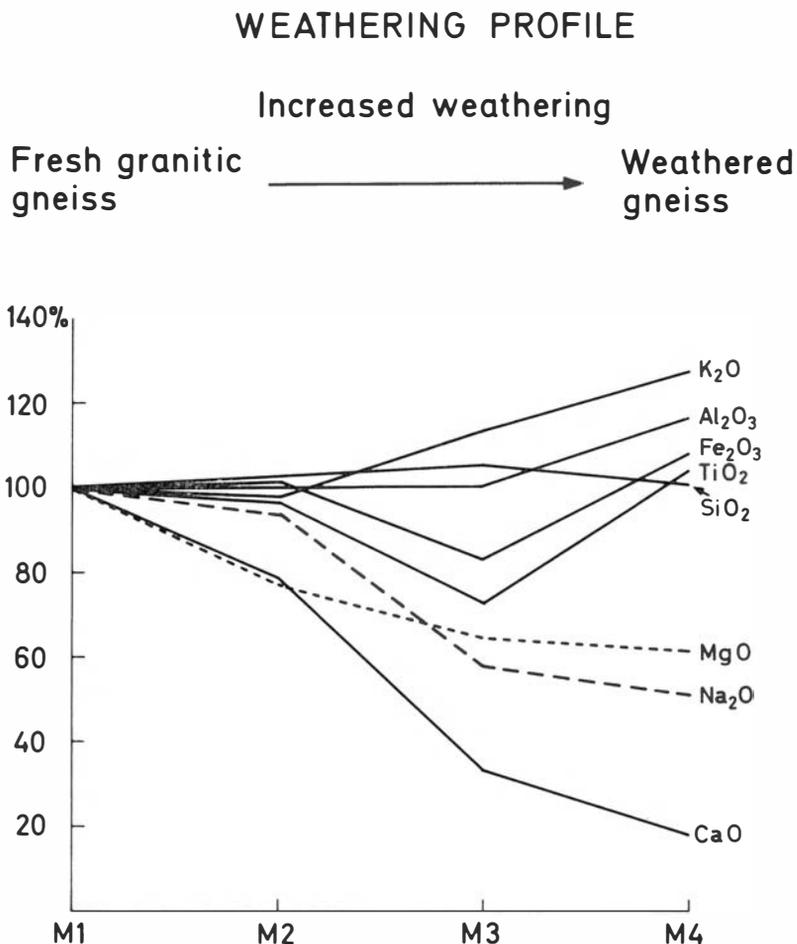Fresh granitic gneiss ⟶ Weathered gneiss

Fig. 5. Relative changes in composition during weathering of a granitic gneiss calculated on a dry rock basis (Table 1). For each element the composition of the unweathered gneiss M1 is taken as 100%.

bolite. Earlier work on the transformation of mica in soils (Millot 1970) shows that biotite is often altered to vermiculite, which again may be transformed into montmorillonite. Kapoor (1972) has described the weathering of biotite to vermiculite and smectite in Norwegian podsol sections in moraines. Expansion after glycol treatment (Fig. 1) shows that in this case we get montmorillonite without any indication of vermiculite.

Chemical changes in the initial stages of weathering

Mineral transformations during weathering are accompanied by important chemical changes in the bulk composition of the rocks. The most important change is the increased water content in the weathered rocks. However, to compare the relative abundance of other elements during different stages of
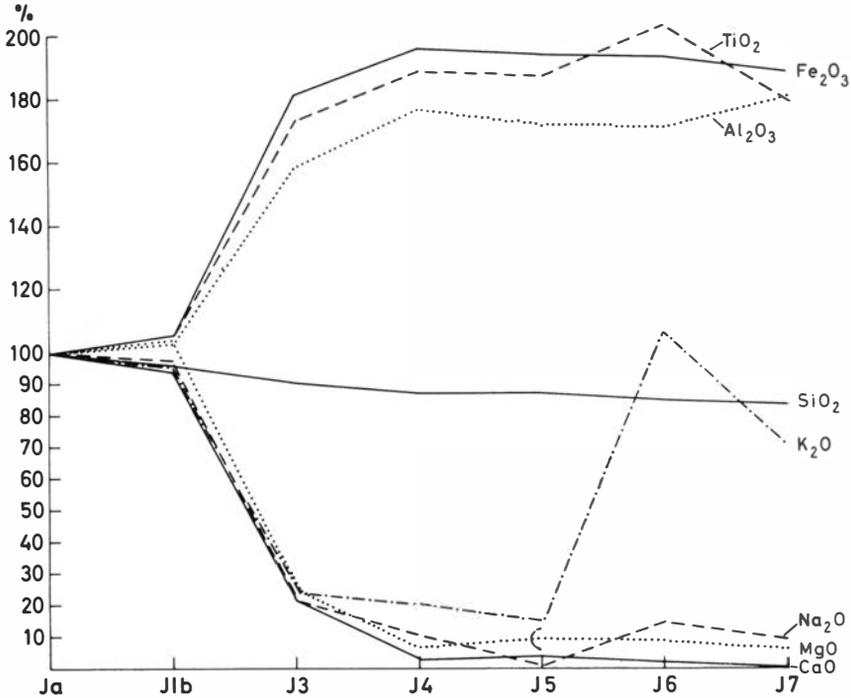
Fig. 6. Relative changes in composition during weathering of an amphibolite calculated on a dry rock basis (Table 2). For each element the composition of the unweathered amphibolite (J1) is taken as 100%.

weathering all analyses have been recalculated on a dry rock basis (ignited samples).

In order to make comparisons easier the content of each element is presented graphically as a percentage of the unweathered samples (M1 and J1) (Figs. 5 and 6). A very rapid leaching of the alkali metals and the alkali earth metals is observed both in the granitic gneiss and amphibolite. This process, however, is most effective in the amphibolite where the Na_2O, MgO and CaO content is reduced to about 10% of its original concentration in sample J4. Potassium appears to be leached in the early stages of weathering but is concentrated again in the overlying soil, probably due to adsorption to clay minerals and enrichment by the vegetation on top of the soil profile. In the same samples, titanium, iron and alumina are increased to about 180% of the values in the unweathered amphibolite.

The geochemical changes accompanying the weathering of the granite gneiss follow the same trends as those of the dolerite but are much slower. Since kaolinite becomes more stable at low K^+/H^+ ratio and low H_4SiO_4 concentration (Garrels & Christ 1965), kaolinite is stable in a basic rock such as amphibolite with little leaching of potassium and silica. For the granitic gneiss, which contains much higher concentrations of silica and potassium, a longer period of leaching is required before kaolinite can become stable. Therefore

the weathering products of the granitic gneiss contain significant quantities of smectite minerals which are not present in the weathered amphibolite. Barshad (1966) found from studies of weathering in California that precipitation alone was the main factor controlling the composition of soils. The nature of the parent rock, according to his study, did not affect the composition of the clay with the exception that illite occurs in soils derived from acid but not from basic rocks.

The difference in annual precipitation (Uganda, Dept. of Lands and Surveys, 1967) at the granitic section (Mutoga 1200 mm) and the amphibolite one (Jinja 1400 mm) does not seem to be great enough to account for the observed mineralogical difference.

Although precipitation and drainage are probably the most important factors controlling the clay mineral distribution in weathered rocks in Uganda too, the composition of the parent rock plays a significant role, particularly in the initial stages of weathering.

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