

BAUXITIC WEATHERING AT MOUNT ZOMBA, NYASALAND

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ABSTRACT

Gibbsite, the dominant mineral in red and yellow earths from Mount Zomba in southern Nyasaland, is derived directly from orthoclase and acid plagioclase (albite-oligoclase). The bauxitization apparently took place at an early stage in the history of the mountain. The evidence suggests that kaolinization succeeds bauxitization in the sequence of weathering, and is related to present-day weathering conditions.

INTRODUCTION

In southern Nyasaland the syenites of Zomba and Mlanje form steep-sided mountain masses, considered to have been emplaced, together with associated smaller intrusions, during a phase of igneous activity at the end of or shortly after the Stormberg volcanic episode at the close of Karroo times, *i.e.*, Rhaetic to Lower Lias (Dixey, Campbell Smith and Bisset, 1955). The weathering features and soils to be described are confined to the upper part of Zomba Mountain, an extensive grassy plateau underlain mainly by syenite, cut by various minor intrusions and dykes. The bedrock may show alteration to a depth of 10 ft. or more. In contrast, the soils are comparatively shallow, averaging 2-4 ft, and belong to the group of 'High Altitude Soils' of Nyasaland, the main characteristics of which are a dark brown to black highly humose topsoil overlying yellowish red, heavy-texture but friable, strongly acid subsoils on granite and syenite (Young, 1960).

Three profiles were examined: a typical red and an adjacent yellow earth from the upper slopes at about 6,000 ft. and a red earth on the lower parts of the plateau at about 5,500 ft. Both the upper slope soils appear to be largely derived either from the syenitic rocks *in situ* or from their detritus. The yellow earth is at the base of an inselberg, from the rock of which it appears to be derived; in the upper horizons there is a distinct layer of boulders on and in the surface of the soil. The red earth on the lower slope has developed from boulders, scree and rubble of mixed character, mainly of syenite but also including granite, vein-quartz and fragments of what appears to have been a fine-grained moderately basic rock-type.

PETROGRAPHY

Weathering of Bedrock. The unweathered bedrock associated with both upper slope soils is medium- to coarse-grained and pale

grey, with conspicuous concentrations of dark minerals. The felspathic constituents are orthoclase and subordinate plagioclase ($Ab_{90}An_{10}$). Quartz is rare. The predominant dark mineral is brown-green hornblende. Pale green augite, biotite, aegirine, ilmenite, and apatite occur in small amounts, with accessory zircon.

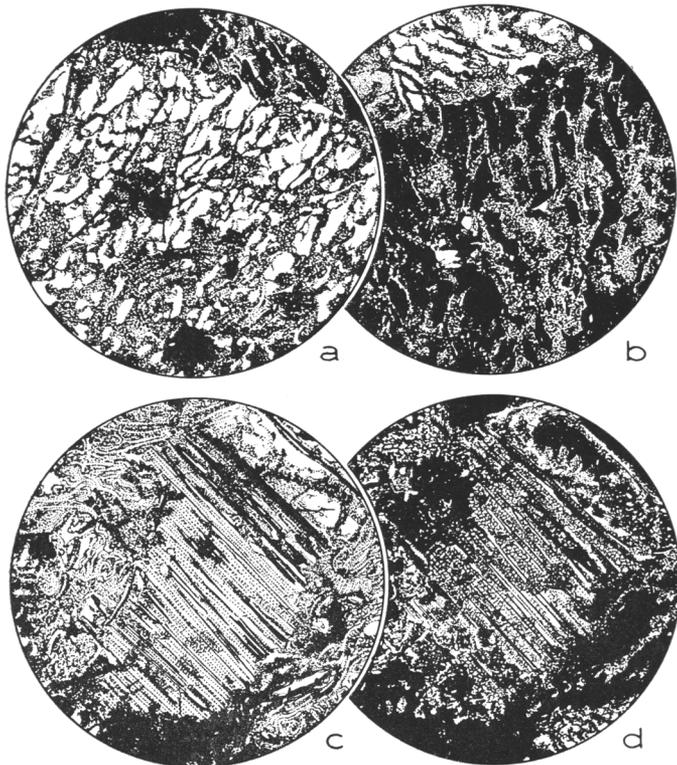


FIG. 1—Drawings showing the alteration of felspar:

- (a) Orthoclase partially altered to gibbsite; clear areas are unaltered orthoclase, whereas gibbsite appears as 'spotty' alteration products. Crossed nicols, $\times 34$.
 (b) Same section, turned through 45° , with orthoclase at position of maximum extinction. Crossed nicols, $\times 34$.
 (c) Plagioclase replaced by microcrystalline gibbsite with preservation of original felspar cleavage. Ordinary light, $\times 34$.
 (d) Same section, crossed nicols, $\times 34$.

The mottled, mainly whitish and reddish brown, weathered rock is friable, but preserves much of its original granitic texture; concentric weathering is well displayed. Under the microscope fine-grained gibbsite can be seen replacing orthoclase and plagioclase, parts of some grains retaining their characteristic optical properties, whereas other grains are completely replaced (Fig. 1, *a-d*). The

gibbsite is colourless to very light tan and its mean refractive index 1.579 ± 0.003 corresponds very closely with the range $1.579 - 1.581$ given by Eyles (1952) for pale grey to white segregations of gibbsite in ferruginous laterite from near Broughshane in Northern Ireland. The degree of crystallinity varies considerably from cryptocrystalline to microcrystalline, in which the crystals range up to 20μ although most are considerably smaller. The individual crystals are mainly randomly arranged, but in places the gibbsite has formed in an ordered manner along original feldspar cleavages, the traces of which are still preserved (Fig. 1, *c* and *d*). Very minor amounts of kaolinite occur in a few rock fragments as fan-shaped aggregates, up to 50μ in size, embedded in gibbsitized feldspar. Initial stages in the alteration of hornblende are revealed by rusty staining along cleavage traces, and, in the more highly weathered parts of the rock, the hornblende may be replaced by reddish brown pseudomorphs giving the goethite X-ray diffraction pattern. In some sections the hornblende is represented by a reticulated structure of intersecting fibres of dark reddish brown goethite, the angles of intersection corresponding to the original amphibole cleavage directions; the interspaces may be empty, or partially or wholly filled with a lighter-coloured variety of goethite. The alteration of augite to goethite parallels that of hornblende. Biotite shows chloritization to a greater or lesser extent. The olive-green chlorite has the refractive indices β and γ near 1.66 , suggesting a variety rich in iron (Winchell and Winchell, 1951), which is confirmed by the high intensity ratio of the $7\text{\AA}/14\text{\AA}$ basal reflections on X-ray photographs (Brindley and Robinson, 1951). Quartz and ilmenite appear unaffected in the weathered rocks, but apatite has been eliminated.

Mineralogy of Soil Horizons. Thin sections of the soil horizons show that the products of alteration of the primary minerals are the same as in the massive rock, gibbsitized feldspar grains, up to 3 mm in size, and reticulated structures of goethite after hornblende being prominent features. Biotite is commonly altered to olive-green chlorite and more rarely to hydrobiotite, accompanied by variable amounts of excremental goethite. Table 1 shows the minerals occurring in the fine sands; the silts have a similar distributive pattern. Rock fragments and mineral grains, including occasional vermiform aggregates of coarse-grained kaolinite up to 2 mm in size, are embedded in a cryptocrystalline clayey groundmass which, on the basis of X-ray and differential thermal examination, consists of gibbsite, kaolin and iron oxides (Table 1). The kaolin of the groundmass corresponds to the *b*-axis disordered mineral of many sedimentary fireclays (Brindley and Robinson, 1947), and relative to gibbsite there is considerably more in the profiles of the red soils than in the underlying weathered rocks.

DISCUSSION

Bauxitic products may apparently originate either directly by weathering of primary rocks (Goldman and Tracey, 1946) or in-

directly by desilication of initially formed kaolinite or halloysite (Allen, 1952; Eyles, 1952). Gibbsite, dominant in the Zomba soils, is derived from the alkali feldspars, orthoclase and sodic plagioclase, and in the weathered syenites its occurrence in the microcrystalline form replacing plagioclase with the preservation of the outline and cleavages is very strong evidence for the process of direct alteration. Harrison (1934) in his classical study of rock weathering in British Guiana indicated that 'the mineral of first and direct formation from the plagioclase feldspar is gibbsite.' This observation pertained to the more basic plagioclases of andesine-anorthite composition, whereas the alkali feldspars yielded not gibbsite but kaolin-type minerals. It seems clear, however, that under a sufficiently aggressive environment all types of feldspar may undergo direct degradation to gibbsite. The kaolin in the red soils appears to be of two distinct generations, the vermicular aggregates of well-crystallized kaolinite, and the finely crystalline kaolin, of the fireclay-variety, subsidiary to gibbsite in the clays.

There is no evidence for the formation of gibbsite from any of the ferromagnesian minerals, the alteration of which is responsible for the reddish brown mottlings characteristic of the weathered rocks. Goethite is the only crystalline phase identified in the alteration of hornblende and augite. Variable amounts of goethite are also produced during biotite weathering, but much of the iron in the mica is apparently retained in the crystal lattice of the secondary chlorite. Quartz, ilmenite and zircon are very resistant to weathering. The stability of quartz under bauxitization has also been demonstrated at Mlanje (Dixey, 1925), where variable amounts of coarse grit are disseminated throughout the deposits because the parent syenite contains quartz veins and quartzose bands and patches.

A close parallel exists between the course of weathering at Zomba and at Mlanje, where, on the Lichenya plateau, the hornblende-syenite is overlain by a quartzose bauxitic capping, averaging 15-30 ft thick (Dixey, 1925). The bauxitization is ascribed by Dixey to an early period in the history of the mountains, and on Zomba Mountain the bauxite or bauxitized syenite can be considered as the parent material of most of the present day soils. The differences between the yellow and the red earths are fairly readily explicable on the basis of site characteristics. The yellow soil, containing appreciable quantities of rock rubble, is apparently of recent derivation from the bauxitized syenite, but the red soils have been more extensively weathered, as is shown by the much greater concentration of the resistant species, quartz, ilmenite and zircon, at the expense of the feldspars and ferromagnesian minerals (Table 1). The latter soils also contain appreciably more kaolin, suggesting that kaolinization succeeds bauxitization in the sequence of weathering, and the coarse-grained kaolinite in vermicular groupings almost certainly represents an *in situ* crystallization. Current weathering conditions probably favour mainly the process of kaolinization.

TABLE 1—Mineralogy of subsoil horizons.

| Sample | Fine sand fraction | | | | Light minerals | | | | Clay fraction | | | | | | | | | | | | | | | |
|--------|--------------------|----|-------------------|----|----------------|---|----------|----|---------------|----|------------|-------|-------------|------|-----------|--|----------|--|--------|--|----------|--|----------|--|
| | Heavy minerals | | Biotite (altered) | | Augite | | Aegirine | | Quartz | | Orthoclase | | Plagioclase | | Kaolinite | | Gibbsite | | Kaolin | | Goethite | | Hematite | |
| A | 10 | 42 | 42 | 5 | <1 | — | — | 55 | 27 | 11 | 7 | 50 | 30 | 5-10 | p | | | | | | | | | |
| B | 57 | 32 | 5 | 2 | <1 | — | — | 9 | 62 | 29 | 9 | 80-90 | <10 | p | | | | | | | | | | |
| C | 12 | 35 | 40 | 12 | <1 | — | — | 50 | 32 | 16 | 2 | 60 | 15-20 | 5-10 | p | | | | | | | | | |

KEY: A—Red earth, upper slope, 35-38 in.; B—Yellow earth, upper slope, 40-43 in.; C—Red earth, lower slope, 24-27 in.

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