

SOME ASPECTS OF KAOLINITE DISSOLUTION BY A LATERITE-INDIGENOUS MICRO-ORGANISM

BY

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SUMMARY. — Geomorphological evidence is presented, which indicates extensive dissolution of kaolinite during lateritisation in Uganda. The results are presented of leaching experiments which explored the effect of a laterite-indigenous micro-organism from Uganda on a saprolite containing predominantly quartz and kaolinite. The extent of the kaolinite dissolution is shown by XRD, DTA, DTG and TG. A comparison is made between the kaolinite before treatment and kaolin surviving treatment, using TEM and EPMA. The study indicates mobilisation of Al. The crystals show a progressive depletion of Al, which is associated with sorption of K. The deterioration of crystallinity is shown by electron diffraction patterns.

RÉSUMÉ. — *Quelques aspects d'élimination de la kaolinite par des micro-organismes prélevés dans un milieu latéritique.* — Il peut être tiré de certaines considérations sur la géomorphologie de l'Ouganda, des arguments en faveur d'une importante élimination de la kaolinite pendant les processus de latérisation. C'est pourquoi des expériences de lessivages ont été menées à l'aide de micro-organismes prélevés dans un milieu latéritique du pays sur une altérite contenant essentiellement du quartz et de la kaolinite. L'importance de l'élimination de la kaolinite avant le traitement et la kaolinite qui a subsisté, a été faite à l'aide du microscope électronique et de la sonde qui lui est associée. Il s'est produit un dépôt progressif de l'aluminium associé à une adsorption de K. La détérioration de la cristallinité apparaît sur les diagrammes de diffraction électronique.

SAMENVATTING. — *Enkele aspecten van de eliminatie van kaolinitet door mikro-organismen voortkomend uit een lateritisch milieu.* — Uit zekere beschouwingen over de geomorfologie van Oeganda kunnen argumenten getrokken worden ten voordele van een belangrijke eliminatie van kaolinitet tijdens de laterisatieprocessen. Daarom werden oplossingsproeven uitgevoerd met behulp van mikro-organismen uit een lateritisch milieu van het land op een lateriet dat uitsluitend kwarts en kaolinitet bevat. Het belang van de eliminatie van het kaolinitet vóór de behandeling en het kaolinitet dat overbleef werd vastgesteld met behulp van de elektronen-mikroscoop en van de toebehorende sonde. Er ontstond een geleidelijke neerslag van Al, samen met een adsorptie van K. De afbrokkeling van de kristalstructuren wordt duidelijk op de diagrammen van elektronische diffractie waargenomen.

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Introduction

Studies of laterite and landsurface development in Uganda have indicated that here kaolinite dissolution has been predominantly congruent during lateritisation. Both Si and Al are "leached" from the profiles. It appears that incongruent dissolution, involving the selective "leaching" of Si and relative accumulation of Al, has not occurred (KAFOL 1970); despite extensive mapping and analyses of laterite by the Geological Survey of Uganda, bauxite has not yet been found. It is the purpose of this paper, first, to present the geomorphological evidence for extensive kaolinite dissolution in both low and high level profiles and secondly, to present evidence for a microbial agent in this dissolution.

1. Geomorphological evidence for kaolinite dissolution

1.1. Low level profiles.

The low level profiles in Uganda, those associated with Wayland's P III (WAYLAND 1931, 1933, 1934) vary considerably. These variations can, nevertheless, be placed in classes corresponding to stages of development in the laterite familial progression. In the first class of profiles, pisoliths form within the range of oscillation of the groundwater-table (Fig. 1). In the dry season, this type of profile can be examined in hand-dug wells, common in central and northern Uganda. The pisoliths are about 1/2-1 cm in diameter, well rounded, dark red (7.5R 3/6-8), unbanded, goethite and haematite impregnated "lithorelics", enclosing undisturbed saprolite. They are matrix supported, the inter-pisolith matrix being predominantly kaolinite and quartz. There is no evidence for relative enrichment of Fe in the profile, merely the segregation of iron originally dispersed in the saprolite (as it is in the saprolite below the zone of oscillation water-table). The frequency of pisoliths varies with lithology and apparently expresses the original iron content of the saprolite.

In the second class of profiles identical pisoliths also occur in the vadose zone above the zone of oscillation (Fig. 1). They are also matrix supported. Their similarity indicates a similar environment of formation, from which it must be concluded either that the zone of oscillation has narrowed or that the present, narrowly-oscillating zone has lowered, leaving in both cases "dead" pisoliths in the vadose zone.

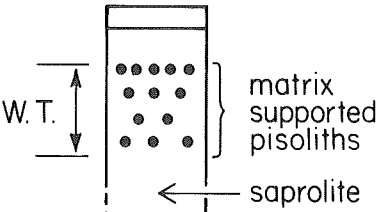
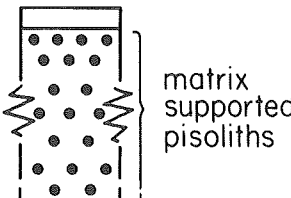
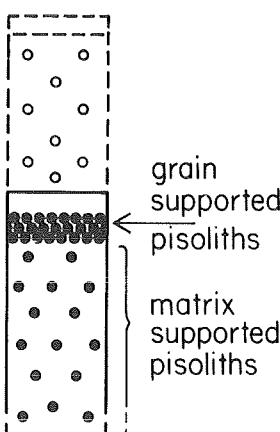
Class 1		contemporaneous pisolith formation within the zone of groundwater — table oscillation
Class 2		large vertical spread of matrix supported pisoliths above groundwater level
Class 3		grain supported pisoliths in the base of the soil, overlying matrix supported pisoliths

Fig. 1. — The three classes of groundwater pisolithic laterite in lowland areas of Uganda.

In the third class of profiles the pisoliths occur not only within the range of oscillation of the water-table and in the vadose zone but they also occur in the base of the mechanically disturbed part of the soil profile (Fig. 1). Here they are “packed”, i.e. grain-supported. The overlying soil and the inter-pisolith material is a red oxisol. The pisoliths have a yellow cutan of goethite (goethan). The pisoliths themselves encapsulate undisturbed saprolite, as in the two previous classes, and they are entirely similar except that the smaller, harder, better rounded specimens dominate. The grain supported fabric

indicates extensive removal of the original kaolinite and quartz matrix, the residue and the breakdown products of the larger softer pisoliths providing "parent material" for the development of the oxisol between and above the pisoliths. Since such sheets of packed pisolithic laterite occupy all catenary positions and drape the interfluvies, it must be concluded that a column of pisolith-bearing saprolite has been reduced in volume in order to yield the concentration ("remanié" or "colluvium"), that is, the landsurface has lowered physically (Fig. 1). Since water-table movement reflects landsurface movement, the zone of oscillation of the water-table must also have lowered. Thus, given the choice of conclusion between narrowing of the water-table oscillation (reduced range) or lowering of the present narrowly-oscillating water-table to explain the second class of profile (Fig. 1), the latter is clearly appropriate. Without wishing to imply that climatic change has not to some extent affected the range of oscillation, it must surely be conceded that the spread of matrix-supported pisoliths in the profile is simply too great — often 15 to 20 metres — for us realistically to postulate that all formed at the same time within a former, more widely oscillating zone. Hydrologists, for example, describe "maximum" oscillations of 3-5 m where there is a monsoon climate (PRASAD & SINHA RAY 1980).

This poses the central problem of how the kaolinite and quartz matrix is removed. Removal could be either mechanical or chemical. Geomorphologists tend to favour the former. A change of climate is popularly evoked, i.e. drier conditions or more markedly seasonal precipitation, which resulted in destruction of the original forest cover thus permitting rainfall to "flush out" the inter-pisolith fines. Without doubt, forest destruction does produce this effect on a small scale but as a general mechanism to explain pisolith concentration it is quite inadequate for two reasons. The sheets of packed pisoliths are often too thick — commonly several and sometimes tens of metres. Recognising the problem of the scale of the "flushing", DE DAPPER (pers. comm.) suggested that removal may be in the context of a series of small retreating pediments, outflushing associated with each increment leading to a thick deposit of packed pisoliths. This nevertheless leaves unsolved the second problem of where all this material has gone. For every metre thick concentration of pisoliths there should be an equivalent deposit of kaolinite and quartz several metres thick. Although local deposits occur these are small and relatively rare. There are no kaolinite deposits which could conceivably correspond with the extensive, thick pisolithic laterites which blanket enormous areas of the tropics. Chemical removal of kaolinite and quartz is clearly indicated.

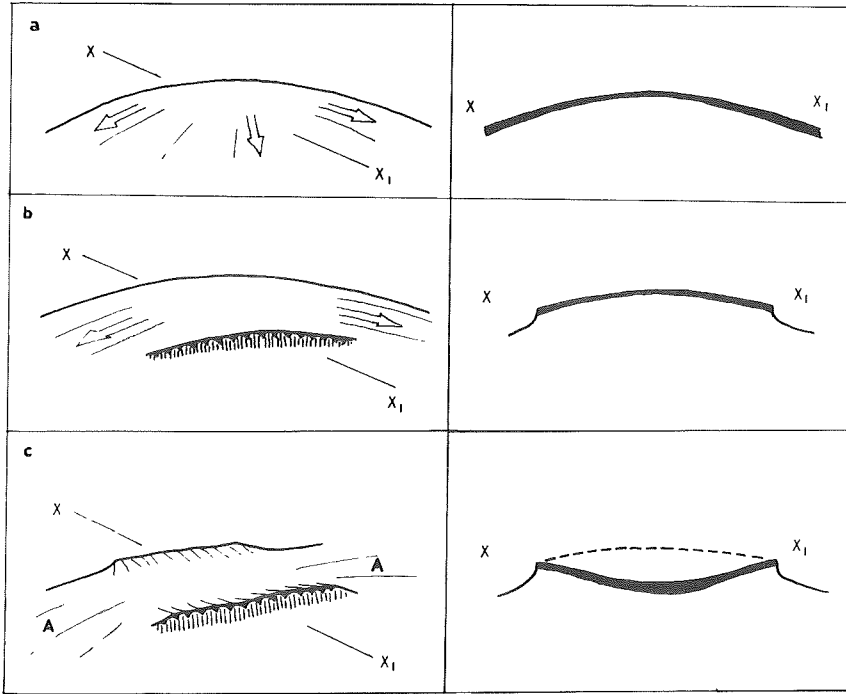


Fig. 2. — An example of relief inversion in Murchison Park, in the Western Rift Valley of Uganda.

The extensive disappearance of the kaolinite and quartz matrix during the process of landsurface downwasting and pisolith concentration is shown by a previously undescribed form of relief inversion which occurs in the Western Rift Valley of Uganda, in Murchison Park. Here, the Pleistocene sediments are in places capped by a thin layer (*c.* 0.5 m) of packed pisolithic laterite, comparable to the material already described. It overlies saprolite containing dispersed pisoliths. The geology and geomorphology of this area has been described by BISHOP (1965). The laterite has been incised in places so that it caps numerous low mesas. In other places it is unincised and drapes rolling interfluvies. Examples were also found of partial incision. Of particular interest was the occurrence of mesas which were undercut on two sides only. Where the laterite cap was incised it stood higher, to form elevated "wings", a few metres above the central area (Fig. 2c). Fig. 2 summarizes the development of this feature. Evidently the slight induration of the laterite profile, where it was incised, was sufficient to terminate the mechanism of

downwasting. At the unincised parts of the interfluvium the mechanism continued (Fig. 2b), eventually lowering the summit below the incised flanks (Fig. 2c). At the open "ends" of the interfluvium (A in Fig. 2c) the layer of pisoliths was deeper than at the exposed wings. Not only does this example of relief inversion provide confirmation for the proposed mechanism of downwasting and concomitant accumulation of pisoliths, based on the familial progression but it also indicates that the kaolinite and quartz matrix is chemically removed since there is a complete absence of kaolinitic deposits in the vicinity.

1.2. High level profiles.

Where the high level laterites of Buganda are permeable, the carapace is often strongly deformed by "pseudo-karst" subsidence features. These have been described elsewhere (McFARLANE 1973). Their scale is often sufficient to suggest that the saprolite below the collapsed carapace is entirely removed rather than that it has merely compacted. This belief was supported by drilling through one of the undeformed mesas, Nsamizi Hill at Entebbe, capped by a relatively impermeable sheet of packed pisolithic laterite, below which the saprolite was unleached (i.e. there was no "pallid" or Fe depleted zone). When the packed pisolithic laterite had been penetrated, the water of circulation was lost, but core recovery was good until at a depth of about 30 ft. (9 m) no core was recovered. The first attempt to case the hole with cement was unsuccessful; redrilling failed to locate the cement (!). The exercise was repeated. The recovered cement core contained small fragments of kaolinite and quartz "float" which had collapsed into what was evidently a large hole in the saprolite inside the hill. Once through the cement, undisturbed saprolite was again penetrated. It is difficult to see how the material could be removed in such a context by a mechanical process. Chemical removal is clearly indicated.

Further support for the belief that kaolinite is physically removed from the high level profiles by a process of dissolution comes from Kako Hill, near Masaka, Western Uganda. There a large cave had been excavated below the carapace of the mesa (as well as several shafts on the subcarapace slope) by prehistoric man, for purposes unknown (LANNING 1954). Inside the cave, a matrix-supported pisolithic laterite was exposed. The pisoliths and larger nodules occurred within a typical white, kaolinite and quartz matrix. Relict rock structures were preserved in the form of near vertical bands with variable pisolith frequency. The cave was roofed by grain-supported pisolithic laterite, which forms the carapace of the hill. One wall of the matrix-supported

pisolithic laterite, exposed in the cave, contained a 5 cm wide vein of quartz which had been replaced by kaolinite "shells". Only "core stones", about 2 cm in diameter, of the original quartz remained in the centre of the former vein. Such neoformation of kaolinite to replace quartz is only possible if A1 is moving downwards through the profile in "solution". There is no possible source for this A1 other than by dissolution of the former kaolinitic matrix between the overlying pisoliths and nodules.

In short, field evidence clearly points to extensive kaolinite dissolution.

2. A microbial role in kaolinite dissolution

Micro-organisms were isolated from a range of high level bauxites and laterites. Details are provided by HEYDEMAN *et al.* (1983). The isolated organisms were introduced to a sterilized saprolite (pallid) from Sydney, Australia, containing predominantly quartz and kaolinite, with a little mica. These leaching experiments showed that several of the organisms effected kaolinite dissolution, as indicated by lower A1 values in the treated solid samples as compared with the untreated solids. The A1 leached from the saprolite was largely undetected in the liquids assayed by the spectrophotometric methods of HILL (1959) presumably because the material is complexed. This kaolinite dissolution supports a postulated microbial role in bauxitisation (McFARLANE 1983). Further research is necessary to determine the nature of the "solutions" with a view to examining whether the A1 liberated has protracted or limited mobility in the natural environment, as this bears on the question of whether it may be locally precipitated as gibbsite, yielding bauxite or may have a sufficiently protracted mobility to allow it to be entirely leached out of the profile. The most effective kaolinite dissolution was achieved by an organism from an unbauitized laterite. This organism came from a depth of 5-6 ft (1.5-2 m) in a high level laterite profile on Nakawungu Hill, Uganda. The laterite and its context have been described elsewhere (McFARLANE 1971). The hill is typical of the Buganda Surface and is strongly modified by post-incision subsidence features including enclosed hollows (PATZ 1965).

Chemical analyses of the quartz/kaolinite saprolite (QKS) before and after the microbial leaching treatment are shown in Table 1. 54.43% by weight of A1 was removed (WILLIAMS 1981). X-ray diffraction (XRD) of the quartz/kaolinite saprolite (QKS) before and after the microbial leaching treatment are shown in Fig. 3. Treatment was for a period of 37 days, by which time the kaolinite peak at 7.08\AA was reduced to less than one third.

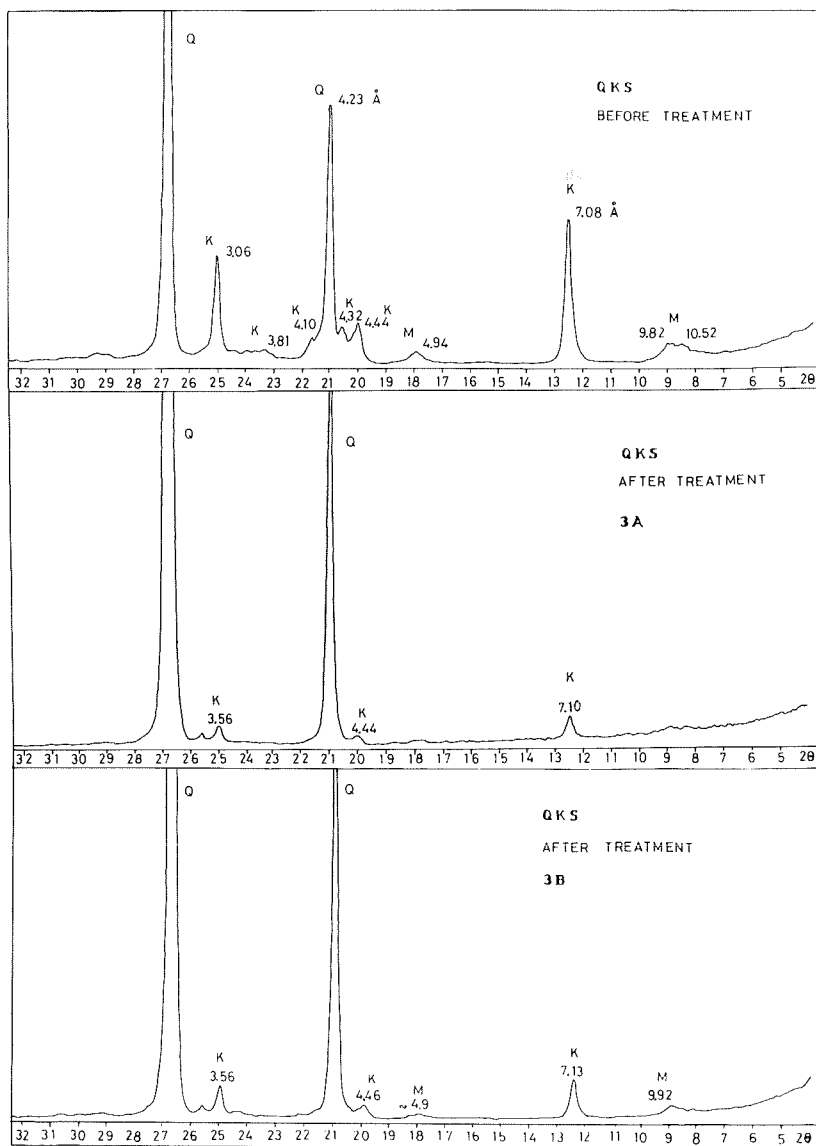


Fig. 3. — X-ray diffraction traces of quartz/kaolinite saprolite (QKS) before and after microbial leaching. 3A and 3B are duplicates. Q = quartz ; K = kaolinite ; M = mica.

Table 1

Solids and liquids assayed by spectrophotometric methods of HILL (1959).

Liquid samples were used directly ; solid samples were first solubilized by fusion with NaOH. (WILLIAMS 1981)

	Wt % Al in solid fraction		Wt % Al in liquid fraction	Final pH of liquid fraction
	assays	mean		
QKS (before treatment)	3.36 3.45	3.4		
3A } after treatment -duplicates	1.90 1.34	1.62	0.0014	3.05
3B }	0.81 1.51	1.16	—	4.50

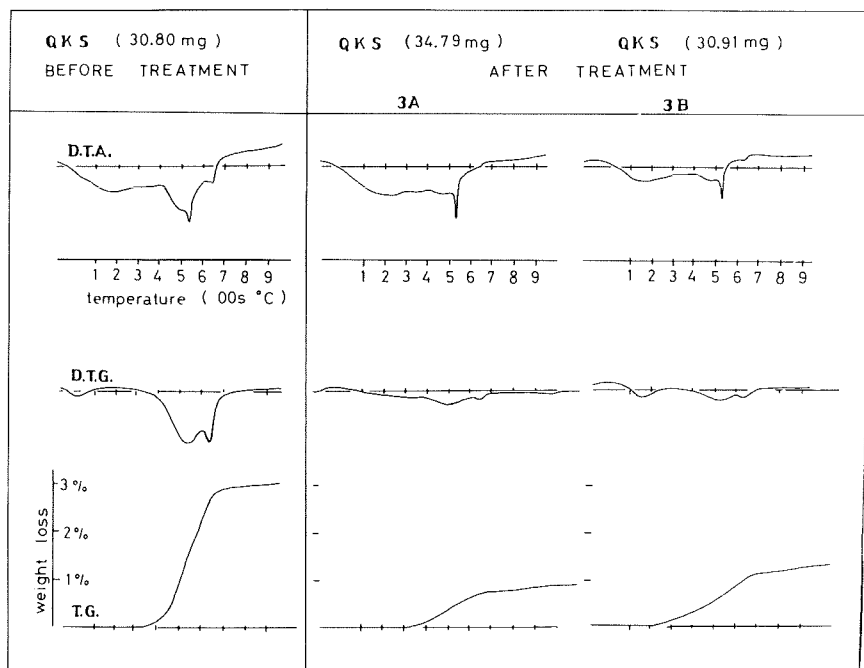


Fig. 4. — Differential thermal analysis, differential thermal gravimetry and thermal gravimetry of quartz/kaolinite saprolite (QKS) before and after microbial leaching (3A and 3B are duplicates).

Note its much reduced size in relation to the quartz peak at 4.23Å. The kaolinite destruction was confirmed by thermal methods in air (Fig. 4).

In order to examine further the effects of the treatment, the kaolinite was separated from the supernatant liquid by centrifugation, resuspended in water and dried on a grid. The chemistry, morphology and crystallinity of 95 kaolinite crystals were examined by electron microscopy and electron probe microanalysis using a Jeol Model 1065, with a KEVEX crystal, Link System 290.

3. Chemistry

3.1. *Al/Si peak ratios.*

Counts per second were recorded at the peak for these elements and corrected for background in an adjacent part of the spectrum. Although peak heights are not quantitative the changing relationships of Al and Si may be examined by comparing the relative peak heights. Distribution of the Al/Si peak ratios of the saprolite before treatment (QKS-untreated) and after treatment (QKS-3A and 3B) are shown in figure 5. The mean Al/Si peak ratio before treatment (35 crystals) was 0.76 and after treatment (60 crystals) was 0.61. Of more significance is the bimodality of the Al/Si peak ratios which suggests a preferred ratio of 0.2 to 0.3 in the Al-depleted material. Of the kaolins surviving treatment a larger proportion were significantly Al-depleted (i.e. with Al/Si peak ratio <0.75), that is 59% as compared with 28% in the original material. 41% of the post-treatment kaolins but only 6% of the untreated material had ratios of less than 0.6.

3.2. *Potassium and other associated elements.*

In order to examine the varying relationships between Al, Si and K, the number of counts per second for the peaks of Al, Si and K were summed and each component expressed as a percentage of the total. These values were plotted on ternary diagrams (Fig. 6). Treated material is shown in (A), untreated in (B). Equal Al/Si peak ratio lines were drawn to allow examination of K variability within the ratio categories 1.0-0.75, 0.75-0.5, 0.5-0.25 and less than 0.25. In both the untreated and treated materials a high proportion (some 80%) of the kaolin with abnormally low Al/Si peak ratios (<0.75) had detectable K peaks. In the untreated material 38% of the kaolin with normal Al/Si peak ratios (>0.75) had detectable K peaks, but after treatment only 24% of the surviving normal kaolin had K peaks. This appears

to suggest that the formation of the strongly adsorbing A1-deficient kaolin effects transfer of K from the normal to the deficient variety. Peaks for other elements associated with the A1-deficient material in the treated samples included Fe in five cases, Ba in two and Zn and Na each in one case.

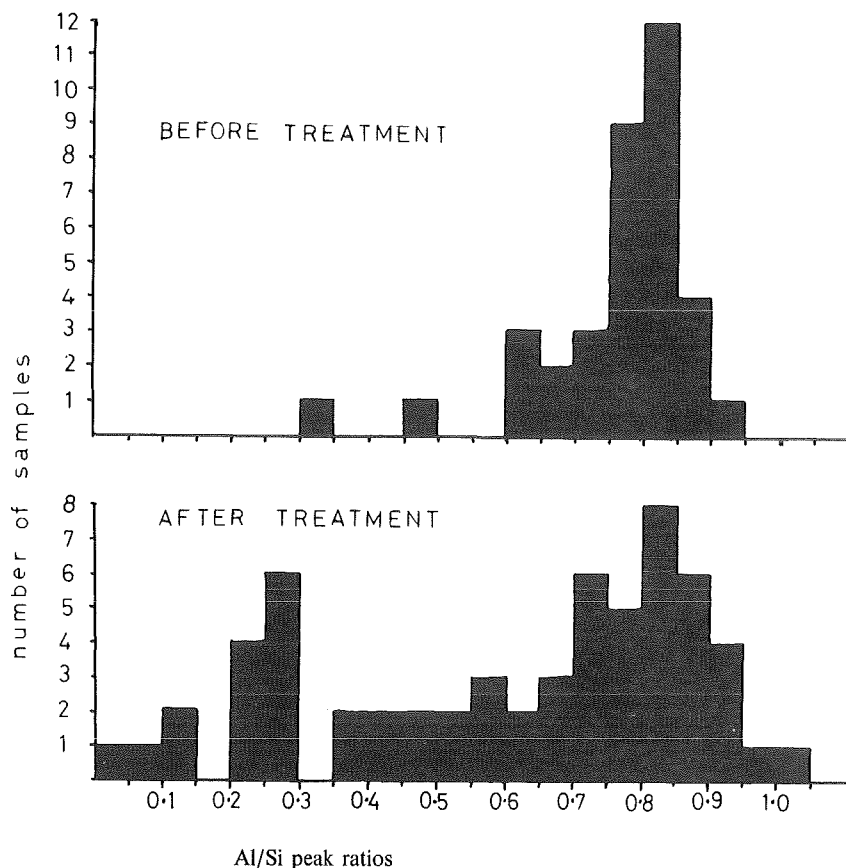


Fig. 5. — Aluminium/silicon peak ratios (EPMA) of kaolin crystals before and after microbial leaching.

4. Kaolinite morphology

4.1. Treated material.

Of the surviving kaolinite, part appeared to be unaffected by the treatment. The crystals were generally hexagonal, with no evidence of A1

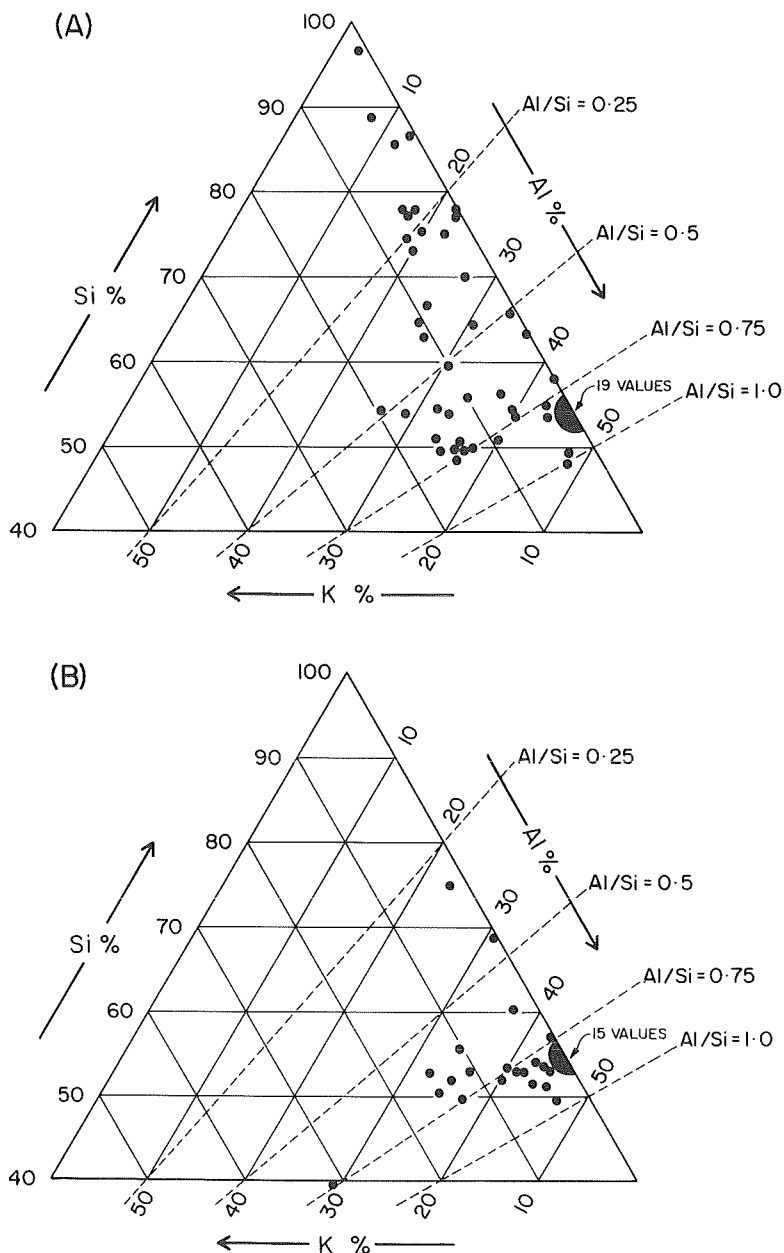


Fig. 6. — The relationships between Al, Si and K peak intensities (EPMA) of kaolin crystals before and after microbial leaching. (A) = treated material; (B) = untreated. For explanation see text.

depletion. Photogr. 1 shows two such crystals. The Al/Si peak ratios are 0.91 and 0.92 for the smaller and larger one respectively. In other cases, although the form of the crystals appeared normal, there was Al depletion. Photogr. 2 shows one such good hexagonal (crystal A) with Al/Si peak ratio of 0.29. In many cases Al depletion was associated with some deterioration of crystal morphology (Photogr. 3). In this case the Al/Si peak ratio was 0.73. In many other cases morphology was very irregular (Photogr. 4). Here the Al/Si peak ratio was 0.14. A further example can be seen in Photogr. 5, where the ratio was 0.78. Another example (crystal B), shown in Photogr. 2, had a Al/Si peak ratio of 0.09. Disaggregation into what appeared to be a mass of crystallites is often associated with serious Al depletion (Photogr. 6). In this example the Al/Si peak ratio was 0.22. Ultimately, disaggregation is extensive, as shown on Photogr. 7; the "grainy" background is gold coating in this case. Photogr. 8 shows the organism adjacent to disaggregated kaolin, with an Al/Si peak ratio of 0.58. Some small crystallites adhering parallel to the upper surface of the organism suggest a positive charge on the bacterial wall, which is relatively rare (CAMPBELL 1983).

4.2. Untreated material.

The majority of the kaolinite crystals examined had good morphology or fairly clear boundaries. Crystal A in Photogr. 9 is an example, with Al/Si peak ratio of 0.83. Another example can be seen in Photogr. 10, crystal A (at least two superimposed crystals) with an Al/Si peak ratio of 0.84. Of interest was the occurrence also of some rather more poorly defined crystals, e.g. crystal B in Photogr. 10, which had an Al/Si peak ratio of 0.67 and also some very poor crystals, of which one is shown in Photogr. 11 (Al/Si ratio of 0.68).

5. Crystallinity

The crystallinity indices of the kaolinite before treatment (QKS) and after treatment (3A and 3B) were calculated from the XRD traces, following the method of HUGHES & BROWN (1979). The index for the pre-treatment kaolinite was 4.16. The material after treatment had a lower index, 2.0 in the case of 3A and 3.33 in the case of 3B.

Photogr. 12 shows the electron diffraction pattern for a pre-treatment kaolinite crystal, the normal crystal A shown in Photogr. 10 (gold coating). The elongation of the light dots indicates the superimposition of crystals.

Photogr. 13 shows the poorer pattern for crystal B on the same plate. Photogr. 14 shows the pattern for one of the few crystals with very poor morphology in the untreated material, the crystal shown in Photogr. 11. Here the scatter of light dots between the gold rings indicates only some very poor ordering.

The Al-depleted kaolin in the treated material (3A and 3B) was very poorly ordered, again with only a scatter of light dots between the gold rings to indicate some ordering. It was not possible to find a relationship between dot pattern or frequency and crystal morphology. For example, the electron diffraction pattern for the dark irregular mass on the left of Photogr. 7, where the Al/Si peak ratio was 0.59, is shown in Photogr. 15. The poor, but more cohesive, kaolin crystal, with Al/Si peak ratio of 0.66, shown in Photogr. 16 (crystal A) had an electron diffraction pattern with fewer inter-ring dots

Fig. 7.

- Photogr. 1. — Two normal kaolinite crystals which survived the microbial treatment. Al/Si peak ratios were 0.91 (the smaller crystal) and 0.92 (the larger crystal).
- Photogr. 2. — After microbial treatment, some crystals retained good morphology (crystal A) but were Al-deficient (Al/Si peak ratio 0.29). Generally Al-depletion was associated with poor morphology (crystal B, with Al/Si peak ratio 0.09).
- Photogr. 3. — Another example of a treated kaolin with poor morphology and low Al/Si peak ratio (0.73).
- Photogr. 4. — In many cases morphology was very irregular in the treated material. In this example the Al/Si peak ratio was 0.14.
- Photogr. 5. — Another example of very poor morphology, after microbial treatment, and low Al/Si peak ratio (0.78).
- Photogr. 6. — Disaggregation into a mass of crystallites was often associated with serious Al-depletion in the treated material. Here the Al/Si peak ratio was 0.22.
- Photogr. 7. — Ultimately disaggregation was extensive in the treated material. The grainy background is gold coating. The electron diffraction pattern for the dark mass on the left (Al/Si peak ratio 0.59) is shown in plate 15.
- Photogr. 8. — The micro-organism, adjacent to disaggregated kaolin (Al/Si peak ratio 0.58).
- Photogr. 9. — In the untreated material the majority of the kaolinite crystals had good morphology or clear boundaries. The example shown here (crystal A) had an Al/Si peak ratio of 0.83. One of the much rarer crystals with very poor morphology is also shown.
- Photogr. 10. — Two more examples of untreated kaolinite. Crystal A (at least two superimposed crystals) had an Al/Si peak ratio of 0.84. (Its electron diffraction pattern is shown on Photogr. 12). Crystal B had less defined boundaries and an Al/Si peak ratio of 0.67. (Its electron diffraction pattern is shown in Photogr. 13).

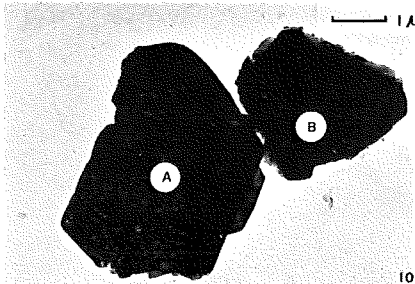
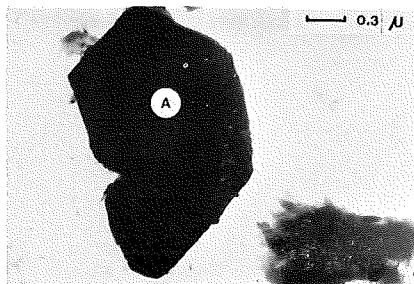
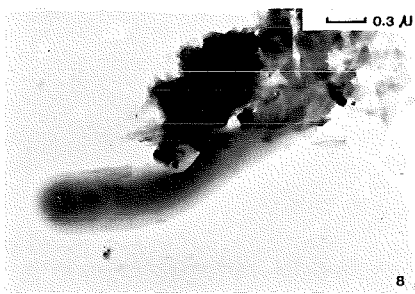
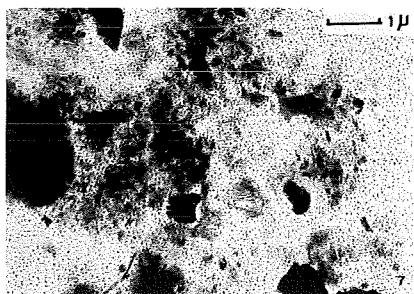
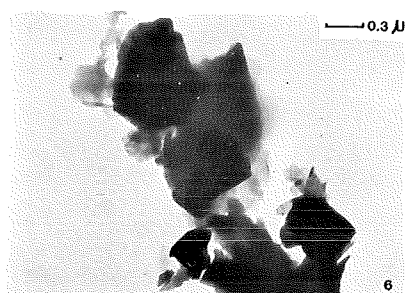
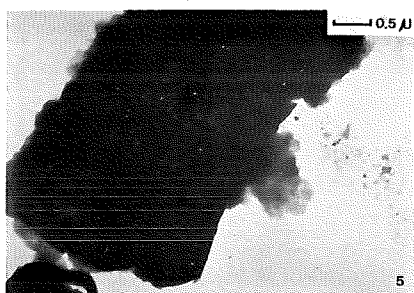
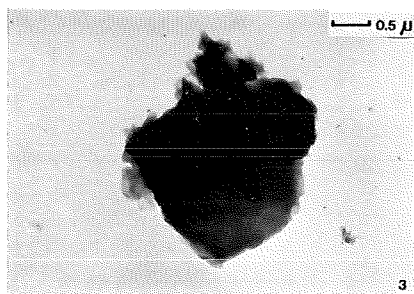
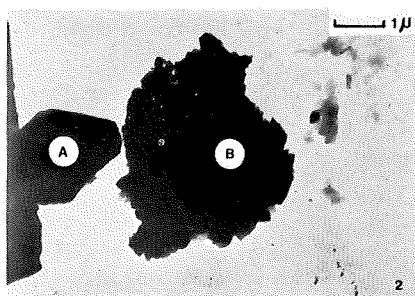
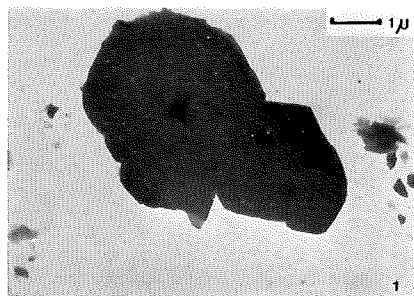


Fig. 7.

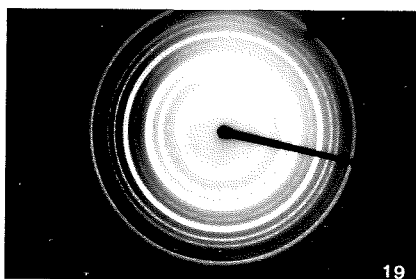
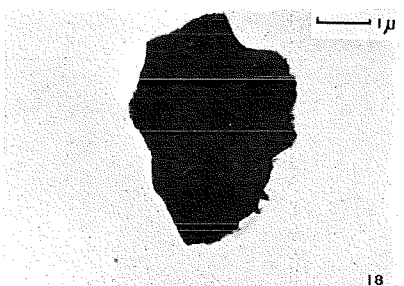
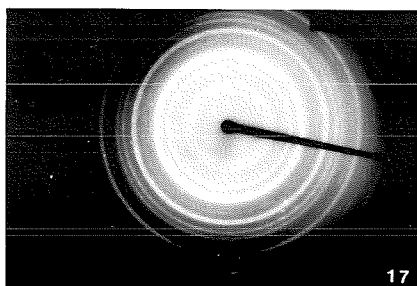
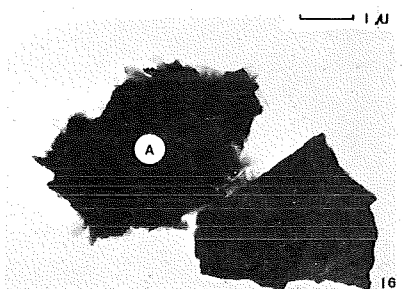
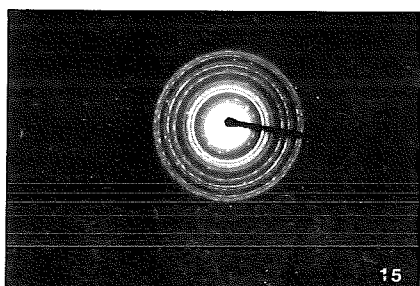
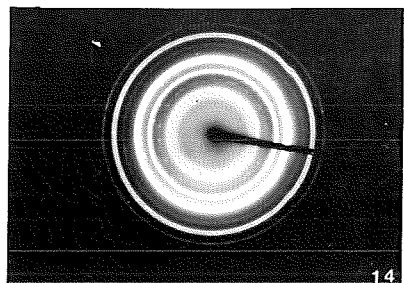
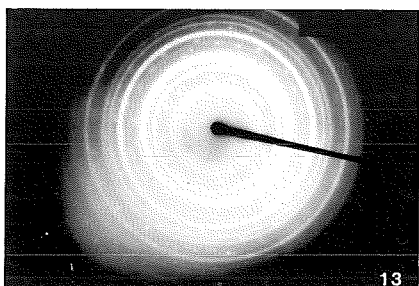
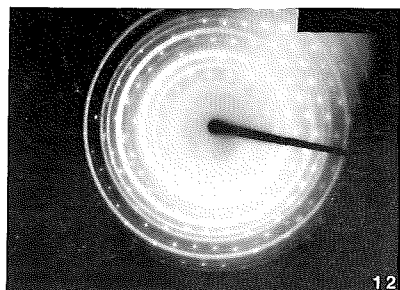
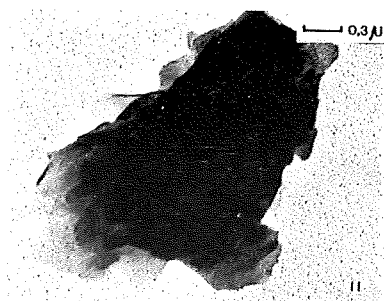


Fig. 8.

(Photogr. 17), while the discrete crystal shown in Photogr. 18, which had an Al/Si peak ratio of 0.67, had an electron diffraction pattern with only rare light dots between the gold rings (Photogr. 19). Further research is needed on this. At present it can only be said that Al-depletion is associated with loss of order.

6. Discussion

The occurrence of a small proportion of Al-depleted kaolins in the original saprolite is important, not only because it indicates that these occur in lateritic materials in nature. It is significant because this Fe-depleted saprolite from Sydney occurs as the matrix between iron segregations. This laterite is essentially similar to the spaced pisolithic laterite in Uganda where the up-profile concentration of pisoliths was attributed, by geomorphological evidence, to chemical removal of matrix kaolinite. Similar concentration occurs in Sydney.

Fig. 8.

- Photogr. 11. — An example of the few crystals with very poor morphology in the untreated material. Al/Si peak ratio was 0.68. The electron diffraction pattern is shown in Photogr. 14.
- Photogr. 12. — Electron diffraction pattern of the untreated kaolinite crystal shown in Photogr. 10 (crystal A). The extension of the dots indicates superimposition of crystals.
- Photogr. 13. — Electron diffraction pattern of a more poorly defined crystal in the untreated material (crystal B on Photogr. 10).
- Photogr. 14. — Electron diffraction pattern of one of the few crystals with very poor morphology in the untreated material (crystal shown in Photogr. 11). Note the scatter of dots between the gold rings, indicating some ordering.
- Photogr. 15. — Electron diffraction patterns for the treated material indicated general disordering. This example is the pattern for the dark irregular mass on the left of Photogr. 7 (Al/Si peak ratio 0.59).
- Photogr. 16. — An example of a discrete, crystal (A) with very poor morphology from treated material. Al/Si peak ratio was 0.66. The electron diffraction pattern is shown in Photogr. 17.
- Photogr. 17. — Electron diffraction pattern for the crystal A (shown on Photogr. 16) from treated material. Note again the scatter of inter-ring dots, indicating some poor ordering.
- Photogr. 18. — A more discrete crystal, from treated material, with Al/Si peak ratio of 0.67. The electron diffraction pattern is shown in Photogr. 19.
- Photogr. 19. — Electron diffraction pattern of the crystal shown in Photogr. 18 (treated material). Again only a scatter of dots between the gold rings indicates some order in the Al deficient "kaolin".

Disordered aluminosilicate material, broadly describable as allophane, has recently been described by BUTT (1983) in W. Australia, where it is responsible for profile induration. Butt suggested that this material is a precursor of kaolinite, which develops from it. Our study suggests that "allophane" can form by the breakdown of kaolinite. This has also been indicated by HUGHES (1980). KILLIGREW & GLASSFORD (1976) suggested that amorphous aluminosilicate matrix associated with Australian sandplains may derive from the disordering of the kaolinite in the underlying pallid zone. It appears that disordering of kaolinite or dissolution may be followed by recrystallization or precipitation lower in the profile in the drier areas of Australia (BUTT, pers. comm.). The slight induration at the free face below the elevated "wings" of the inverted summits in the Western Rift Valley of Uganda may also be attributable to aluminosilicate cementation rather than iron since there the iron is largely segregated into pisoliths dispersed in the saprolite.

Of the treated material, some of the kaolinite is totally unaffected by microbial activity, some is Al-depleted and some is completely destroyed. This variability indicates that proximity to the organisms is important rather than that kaolinite destruction is attributable to the organisms altering the overall pH of the solution in a critical way. Had the general pH been important such extreme local variations would be inexplicable. This poses the question of whether microbial activity effects local pH-controlled dissolution or whether biological complexing occurs. It is conceivable that pH-controlled mobilization of Al at microsites may be maintained when the solubilized materials are washed through the profile where higher pH values occur, but this would depend to a considerable extent on the concentration. Material microbially complexed would be free from these constraints, but until further studies are made of the dissolution products the extent of mobilization, be it local or protracted, remains an open question. Since micro-organisms occur as a discontinuous but ever-changing mosaic within the weathering profile, over a protracted period of time the kaolinite, in total, may be destroyed by their action, allowing the Fe-rich pisoliths to become concentrated, as suggested in the model of pisolithic laterite accumulation. Microbial dissolution of kaolinite accords with the karstification of the Buganda Surface mesas. Any slight depression acts as a focus for both surface water and soil accumulation, and the denser vegetation in such situations would provide a richer source of nutrients for micro-organisms, favouring accelerated dissolution at such sites. Indeed the large-scale summit inversion described by TRENDALL (1962) has already been linked with the deterioration of the forest

vegetation to grass at the periphery of the mesas, this leading to induration and loss of permeability (McFARLANE 1976, p. 99). In the centres of the mesas where forest survives, permeability and a nutrient supply are maintained and here the summits have subsided to the extent that they are lower than the periphery, giving a "soup-plate" form.

It is not yet known how the quartz is removed from the Ugandan profiles, nor the solid Si residue of the activity of this particular organism. In Uganda both are evidently removed, as is the A1 in "solution". In contrast, some profiles in Australia show accumulation of quartz sand in the upper horizons, while A1 is precipitated as gibbsite lower in the profile and in some profiles Si is precipitated at some depth as silcrete or opal. Understanding the ultimate nature of laterite profiles appears to rest heavily on an understanding of the activity and interaction of the microbial population as a whole, on the precise nature of the "dissolved" materials and on the environmental conditions which affect the extent of their mobility. It is often claimed that the study of laterite must begin with an understanding of the pH controls on solubility. There is growing evidence from the field that the over-riding importance of the pH control may have been exaggerated by the ease with which its study can be brought back to the laboratory, this leading to a questionable dominance of this factor among the many which interact to produce the residuum. The frequency with which field observations lead to deductions concerning element mobilisation which contradict the behaviour expected from the gross pH of the profiles and from the laboratory studies of pH-controlled mobility point increasingly to the need for more serious work on biological complexing.

7. Conclusions

Extensive kaolinite dissolution occurs in both high and low level laterites in Uganda. An organism from a high level laterite profile in Uganda has been shown in laboratory experiments to effect kaolinite dissolution. The solid residue of the leaching experiments contained less A1 than the original material. The bulk of the kaolin was destroyed by the treatment. Of the surviving "kaolin" crystals the majority were A1-depleted. Although in some cases crystal morphology remained apparently unaffected by loss of A1, in most cases loss of A1 was associated with poor morphology and ultimate disaggregation into a mass of crystallites. A high proportion of the depleted material had sorbed K. Since, of the crystals unaffected by the treatment, a lower proportion had absorbed K in comparison with the untreated material, transfer of K from the unaffected to the depleted kaolins is indicated. Loss

of Al is associated with lowered crystallinity indices and disordering is confirmed by electron diffraction patterns.

In the laboratory the effect, upon kaolinite, of an organism from a natural situation in which extensive kaolinite dissolution has been deduced from field work leads to the conclusion that it can explain the dissolution in nature. Further research is needed into the role of micro-organisms in the differential "leaching" which yields lateritic and bauxitic residua, particularly in the high level profiles, formerly presumed to be "dead".

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REFERENCES

- BISHOP, W. W. 1965. Quaternary geology and geomorphology in the Albertine Rift Valley, Uganda. — *Spec. Pap. geol. Soc. Am.*, **84** : 293-321.
- BUTT, C. R. M. 1983. Aluminosilicate cementation of saprolites, grits and silcretes in Western Australia. — *J. geol. Soc. of Australia*, **30** : 179-186.
- CAMPBELL, R. 1983. Microbial Ecology (2nd edition). — Blackwell Scientific Publications, Oxford, 191 pp.
- HEYDEMAN, M. T., BUTTON, A. M. & WILLIAMS, H. D. 1983. Preliminary investigation of micro-organisms occurring in some open blanket lateritic silicate bauxites. — *In* : Proceedings of the IInd International Seminar on Laterisation Processes (São Paulo, Brazil, 1982), pp. 225-236.
- HILL, U.T. 1959. Photometric determinations of aluminum in steel. — *Analytical Chemistry*, **31** : 429-431.
- HUGHES, J. C. 1980. Crystallinity of kaolin minerals and their weathering sequence in some soils from Nigeria, Brazil and Colombia. — *Geoderma*, **24** : 317-325.
- HUGHES, J. C. & BROWN, G. 1979. A crystallinity index for soil kaolins and its relationship to rock, climate and soil maturity. — *J. Soil Science*, **30** : 557-563.
- KAFOL, N. 1970. An investigation into the possible sources of raw material for an aluminium industry in Uganda. — Rep. geol. Dep. Uganda (unpublished), NK/1, 31 pp.

- KILLIGREW, L. P. & GLASSFORD, D. K., 1976. Origin and significance of kaolin spherules in sediments of south western Australia. — *Search*, **7** : 393-394.
- LANNING, E. C. 1954. Notes on certain shafts in Buganda Toro. — *Uganda J.*, **18** : 187-90.
- McFARLANE, M. J. 1971. Lateritization and landscape development in Kyagwe, Uganda. — *Quart. J. geol. Soc. Lond.*, **126** : 501-539.
- McFARLANE, M. J. 1973. Laterite and topography in Buganda. — *Uganda J.*, **36** : 9-22.
- McFARLANE, M. J. 1976. Laterite and landscape. — Academic Press, 151 pp.
- McFARLANE, M. J. 1983. The temporal distribution of bauxitisation and its genetic implications. — *In* : Proceedings of the IInd International Seminar on Lateritisation Processes (São Paulo, Brazil, 1982), pp. 197-208.
- PATZ, M. J. 1965. Hill-top hollows — further investigations. — *Uganda J.*, **29** : 225-228.
- PRASAD, K. K. & SINHA RAY, S. P. 1980. Role of ground water in the lateritisation of hills around Gauhati, Assam. — *In* : Proceedings of the Ist international Seminar on Lateritisation Processes (Trivandrum, India, 11-14 December 1979), pp. 391-400.
- TRENDALL, A. F. 1962. The formation of apparent peneplains by a process of combined lateritization and surface wash. — *Z. Geomorph.*, **6** : 183-197.
- WAYLAND, E. J. 1931. Summary of progress of the Geological Survey of Uganda. — *Summ. Prog. geol. Surv. Uganda*, 1919-29.
- WAYLAND, E. J. 1933. The peneplains of East Africa. — *Geogr. J.*, **82** : 95.
- WAYLAND, E. J. 1934. The peneplains of East Africa. — *Geogr. J.*, **83** : 79.
- WILLIAMS, H. D. 1981. Micro-organisms as agents of geological change. — Unpub. Report, Department of Microbiology, Reading University, 26 pp.

DISCUSSION

M. C. Van Oosterwijk-Gastuche. — If the observation you made in Uganda, that some micro-organisms are able to dissolve clay minerals, could be generalised, it would oblige us to change utterly all our views on the mechanism of laterization.

Let me tell you that a long time ago, being in charge by INEAC to make an extensive study of the clay fraction of former Belgian Congo, the same "horrid" crystals as those you have shown appeared to me very frequently at the electron microscope. Even those micro-organisms remained "stuck" to the clay after the classical H_2O_2 treatment. I remember that such clays peptised with extreme difficulty. I did even once a chemical analysis on one of those clays which surprised me, since instead of being Al-rich as I expected, it was anormally Si-rich !

We did not focus the attention on these facts we could not explain in the several publications issued at that time.

