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MINERALOGICAL CHARACTERISATION AND PROCESSING OF SOME INDUSTRIAL MINERALS FROM UGANDA

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1. INTRODUCTION

This report describes the mineralogical characterisation and processing of several industrial minerals collected by Dr DJ Morgan in October 1991 during a visit to Uganda (Visit report WG/91/31R). The industrial minerals included raw materials (see Table 1) from African Ceramics Ltd (Mutaka kaolin, feldspar and ball clay) and samples collected by the Geological Survey and Mines Department Uganda (the remaining kaolin, talc and diatomite). The aim of this study was to assess their quality for various applications, especially ceramic manufacture. This work was carried out as part of the ODA/BGS project "Minerals for Development".

2. SAMPLES

Table 1. Industrial minerals examined from Uganda

Samples	Locality	Description
Namasera kaolinite	Entebbe	Pinkish-brown, kaolitinised sandstone with fine sub-millimetre laminae and visible quartz, mica and iron oxide.
Mutaka kaolinite	SW Uganda	A very white, friable kaolin-rich sandstone, containing large quartz crystals (up to several cm in diameter).
Koki kaolinite	S of Mbirizi-Lyantonde road	A finely laminated, pinkish-white mudstone, with a friable nature and powdery surface.
Kesinga 'talc'	Kasesi District	A dark greenish-brown, fine grained material with fine laminations and a soapy texture.
Kyamuhunga 'talc'	SW Uganda	A light green, fine grained material with a shiny lustre, soapy texture and fine laminations.
Pakwach diatomite	NW Uganda	A very white, lightweight and fine grained material, with brittle fracture and a powdery surface.
Mutaka feldspar	SW Uganda	A light brown, coarsely crystalline feldspar with a light brown dust coating.
Mukona ball clay		A homogeneous, brownish-grey clay with iron-oxide staining.

3. METHODS

X-ray diffraction was used to determine the mineralogy, using a Phillips PW 1700 X-ray diffractometer. Randomly oriented mounts were scanned over 3 - 50 °2θ to determine bulk mineralogy and oriented clay fraction mounts were scanned over 1.5 - 30 °2θ to determine clay mineralogy. The traces were interpreted with reference to the JCPDS database. Thermogravimetric analysis (TG) was used to determine the quantitative mineralogy, specifically kaolinite. Major-element chemistry of the Mutaka feldspar was determined by X-ray fluorescence analysis of a fused glass disc using a Phillips PW 1480 X-ray fluorescence spectrophotometer.

Particle-size distributions were determined by wet screening and/or X-ray sedigraph analysis. Brightness measurement was carried out by reflectance spectrophotometric analysis of unfired and fired material (2 hours at 1050°C), using a barium sulphate standard and values quoted are at 4700Å. The Atterberg liquid and plastic limits of the Mukona ball clay were determined and the plasticity index was calculated from these. Scanning electron microscopy (SEM) was used to examine the surface texture of the Pakwach diatomite, using a Cambridge Stereoscan SEM.

Wet processing of the kaolinite was carried out by attrition scrubbing and wet screening (2 mm to 63 μm). Hydrocycloning was used to produce clay concentrates from the <63 μm fractions. A small glass hydrocyclone, separating at approximately 10 μm, produced an underflow (material mainly >10 μm) and an overflow (material mainly <10 μm). The overflow products were examined by transmission electron microscopy (TEM) in order to study the kaolinite particle morphology and particle thickness was determined by metal shadowing.

4. RESULTS

4.1. Namasera kaolinite

The Namasera kaolinite contains mainly quartz and kaolinite (18%) with trace amounts of mica and iron oxides. The clay fraction is mainly kaolinite and quartz, with a trace of mica (Table 2). The +63 μm fractions contain mainly quartz, with the amount of mica and iron oxides increasing with decreasing particle size. The -63 μm fraction contains 73% kaolinite at a recovery of 94% of that present in the original sample, with 51% of the particles being <2 μm in size. Due to a high proportion of iron oxide in the coarse silt, this fraction was further wet screened on 32 μm and the -32 μm fraction used as the hydrocyclone feed.

The hydrocyclone feed has a high kaolinite content (77%) and high recovery (88%), with 69% of the particles <10 μm and 44% <2 μm in size. The underflow has a reduced kaolinite content (66%) but has a high recovery (58%) and a relatively coarse particle size, with only 29% < 2 μm in size. The overflow has a high kaolinite content (82%), low recovery (31%) and is very fine with 79% <2 μm in size (Table 3 and Figure 1). The overflow has a raw brightness of 50% and a fired brightness of 66% (Table 5 and Figure 4). The TEM study of the overflow shows the kaolinite to consist of euhedral hexagonal plates, ranging from 0.1 - 1.25 μm in diameter (averaging 0.5 μm) and 0.01 - 0.14 μm in thickness (averaging 0.04 μm), with an aspect ratio of 15.4. Figure 10 shows a typical assemblage of particles and Figure 11 shows a kaolinite plate with visible cleavage and metal shadow.

4.2. Mutaka kaolinite

The Mutaka kaolinite contains mainly kaolinite (65%), with a small amount of K-feldspar, quartz and mica. The clay fraction contains mainly kaolinite, with a small amount of quartz and a trace of mica (Table 2). The +63 μm fractions contain mainly quartz, feldspar, mica and iron oxides. The -63 μm fraction, which was used as the hydrocyclone feed, has a high kaolinite content (82%), a high recovery (93%) and contains 29% particles <2 μm in size.

The hydrocyclone underflow has a reduced kaolinite content (79%), a high recovery (57%) and is relatively coarse with only 15% <2 μm. The overflow has a high kaolinite content (87%), a low recovery (35%) and 54% particles <2 μm in size (Table 3 and Figure 2). The overflow has a raw brightness of 80% and a fired brightness of 87% (Table 5 and Figure 5). TEM of the Mutaka kaolinite overflow shows mainly subhedral to rounded kaolinite plates and halloysitic rods. The kaolinite ranges from 0.05 - 1.18 μm in diameter (averaging 0.4 μm) and 0.01 - 0.26 μm in thickness (averaging 0.09 μm). Aspect ratio averages at 5.6. Figures 12 and 13 show the typical assemblage of plates and rods.

4.3. Koki kaolinite

The Koki kaolinite contains mainly quartz, with a small amount of kaolinite (16%), mica and plagioclase feldspar, with a trace of K-feldspar. The clay fraction is mainly quartz, with a small amount of kaolinite and mica, and a trace of feldspar (Table 2). The +63 μm fractions are mainly quartz, mica and feldspar. The -63μm fraction, which is used as the hydrocyclone feed, has a low kaolinite content (16%), a high recovery (99%) and is relatively coarse with only 21% <2 μm.

The hydrocyclone underflow product has a very low kaolinite content (10%), high recovery (49%) and is relatively coarse with only 11% <2 μm. The overflow has a low kaolinite content

(23%), a high recovery (50%) and is relatively fine with 41% particles <2 μm in size (Table 3 and Figure 3). The overflow has a raw brightness of 57% and a fired brightness of 66% (Table 5 and Figure 6). TEM of the Koki kaolinite overflow shows the kaolinite to consist of euhedral hexagonal plates, which range from 0.38 - 0.96 μm in diameter (averaging 0.63 μm) and 0.02 - 0.1 μm in thickness (averaging 0.06 μm), with an average aspect ratio of 12.9. Figures 14 and 15 show typical kaolinite crystals, with visible cleavage and metal shadows.

4.4. Kesinga and Kyamuhunga 'Talc'

Both bulk and clay fractions of the Kesinga and Kyamuhunga 'talc' samples consist mainly of chlorite, with only a small amount of talc being identified (Table 2).

4.5. Pakwach diatomite

The Pakwach diatomite contains mainly amorphous silica and kaolinite (39%), with a small amount of quartz and a trace of smectite. The clay fraction is mainly kaolinite, with a small amount of quartz and smectite and a trace of mica (Table 2). Under the scanning electron microscope the sample was seen to consist largely of diatoms with the appearance of segmented porous hollow tubes; and these have been tentatively identified as *Melosira sp*. This is a planktonic genus typical of a deep freshwater environment and preservation of whole diatoms, as in this sample, requires low energy pelagic sedimentation. The fine-grained matrix is kaolinite, as confirmed by energy dispersive analysis and it is present in about the proportion indicated by TG. Figure 8 shows a single diatom segment approximately 20 - 25 μm in diameter and about 10 μm long. Figure 9 shows single diatom segments and a chain of diatoms (about 100 μm long) in a matrix of fine-grained kaolinite.

4.6. Mutaka feldspar

The Mutaka feldspar was wet screened on 1 mm and 63 μm sieves in order to remove the coating around the feldspar grains. The +1mm feldspar, which forms 92.8% of the sample, contains mainly K-feldspar and albite. This is confirmed by the chemistry, which indicates the presence of 64.82% SiO_2, 19.41% Al_2O_3, 0.53% Fe_2O_3, 2.04% Na_2O and 13.23% K_2O. The -1mm +63 μm fraction, which forms 3.8% of the sample, contains mainly K-feldspar and albite, with a small amount of kaolinite and quartz and a trace of mica. The -63 μm fraction, which forms 3.4% of the sample, contains mainly kaolinite (65%) and K-feldspar, with a small amount of albite and quartz and a trace of mica (Tables 2 and 4).

4.7. Mukona ball clay

The Mukona ball clay contains mainly quartz and kaolinite (38%), with a small amount of albite and a trace of smectite. The clay fraction is mainly kaolinite and quartz, with a small amount of smectite and a trace of mica (Table 1). It contains 3.4% of particles +63 μm, 75.8% <10 μm and 44.9% <2 μm. The liquid limit is 30, the plastic limit 17 and the plasticity index 13. Raw brightness is 38% and the fired brightness is 46% (Table 5 and Figure 7).

5. CONCLUSIONS AND DISCUSSION

5.1. Kaolinites

The Namasera kaolinite can be upgraded to a product grading 82% kaolinite, with 79% particles <2 μm in size. However, the product has a poor colour that is not significantly improved on firing and is probably only useful for applications requiring low-brightness kaolin, such as agricultural pesticide carriers. The Mutaka kaolinite can be upgraded to a product grading 87% kaolinite, with 54% particles <2 μm in size and having high brightness (80% unfired and 87% fired). This kaolinite is worthy of further investigation for its potential use in paper and ceramics (and is in fact already being used as a ceramic raw material). The Koki kaolinite could not be appreciably upgraded, has a low clay content and poor colour, and is probably only of use for applications requiring low grade kaolin.

5.2. 'Talc'

The Kesinga and Kyamuhunga 'talc' contain mainly chlorite and are probably only of potential use as low grade fillers.

5.3. Pakwach diatomite

The Pakwach diatomite is very white and contains a large proportion of diatoms in a kaolinite matrix. This is a very promising material worthy of further more detailed investigations. It is likely that both high-grade diatomite and kaolinite could be produced from the same material, by either air classification or hydrocycloning.

5.4. Mutaka feldspar

The Mutaka feldspar is an off-white K-feldspar, with a small amount of albite and low levels of impurities, such as Fe_2O_3 and TiO_2. This material is already in use as a ceramic raw material.

5.5. Mukona ball clay

The Mukona ball clay is a poor quality kaolinite, with low plasticity, high silt content and poor fired colour. This material is already in use as ceramic raw material.

Table 2. Mineralogy of some Ugandan industrial minerals

Sample	Mineralogy
Namasera kaolinite	
Bulk	Quartz ****, kaolinite 18%, mica *, iron oxides *.
<2 µm	Quartz ****, kaolinite ***, mica *.
Mutaka kaolinite	
Bulk	Kaolinite 65%, K-feldspar **, quartz **, mica *.
<2 µm	Kaolinite ****, quartz **, mica *.
Koki kaolinite	
Bulk	Quartz ****, kaolinite 20%, mica **, plagioclase **, K-feldspar *.
<2 µm	Quartz ****, kaolinite **, mica **, Plagioclase *, K-feldspar *.
Kesinga talc	
Bulk	Chlorite ****, talc **.
<2 µm	Chlorite ****, talc **.
Kyamuhunga talc	
Bulk	Chlorite ****, talc **.
<2 µm	Chlorite ****, talc **.
Pakwach diatomite	
Bulk	Amorphous silica ****, kaolinite 39%, quartz **, smectite *.
<2 µm	Kaolinite ****, quartz **, smectite **, mica *.
Mutaka feldspar	
+1 mm	K-feldspar ****, albite ***.
-1mm +63 µm	K-feldspar ****, albite ***, kaolinite **, quartz **, mica *.
-63 µm	Kaolinite 65 %, K-feldspar ***, albite **, quartz **, mica *.
Mukona ball clay	
Bulk	Quartz ***, kaolinite 38%, albite **, smectite *.
<2 µm	Kaolinite ****, quartz ***, smectite **, mica *.

Key : **** = >50 weight %, *** = 20 - 50 wt %, ** = 7 - 20 wt % and * = <7 wt %

Table 3. Ugandan kaolinite hydrocyclone separation

Sample	Weight % of head	Kaolinite Wt %	Recovery Wt %	< 10 μm Wt %	< 2 μm Wt %
Namasera kaolinite					
Feed	20.7	(77.2)	88.8	69.4	43.5
Underflow	14.5	66.0	58.0	57.5	28.5
Overflow	6.2	82.0	30.8	97.0	78.5
Mutaka kaolinite					
Feed	73.3	82.0	92.5	65.0	29.0
Underflow	47.1	79.0	57.4	48.5	15.0
Overflow	26.2	87.0	35.1	97.0	54.0
Koki kaolinite					
Feed	99.1	16.0	99.1	65.5	20.5
Underflow	68.4	10.0	48.8	51.5	11.0
Overflow	30.7	23.0	50.3	96.5	40.5

Table 4. Chemical analysis of Mutaka feldspar, Uganda

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total
64.82	0.01	19.41	0.53	0.009	0.09	0.06	2.04	13.23	0.13	0.39	100.72

Table 5. Brightness of kaolinites and ball clay, Uganda.

Sample	Wavelength 4700 Å	4900 Å	5500 Å	5800 Å
Namasera kaolinite overflow				
Raw	49.9	49.8	57.0	64.4
Fired	65.8	64.3	66.3	72.4
Mutaka kaolinite overflow				
Raw	80.2	81.7	84.7	86.6
Fired	87.1	86.5	81.0	89.9
Koki kaolinite overflow				
Raw	56.9	56.3	60.9	66.8
Fired	66.1	64.8	67.4	74.7
Mukona ball clay				
Raw	37.8	38.7	40.7	40.5
Fired	46.3	46.6	54.8	61.2

N.B. These figures are percentage reflectance values taken in comparison to a $BaSO_4$ standard using an EEL spectrophotometer over 4700 - 5800Å.

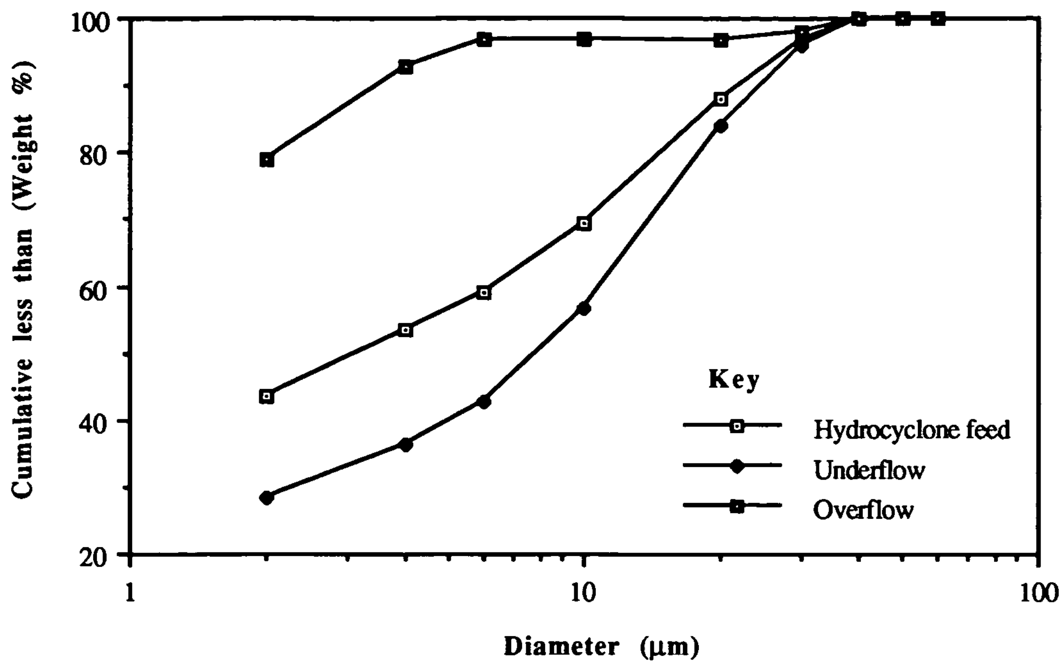

Figure 1. Particle-size distributions of Namasera kaolinite hydrocyclone products

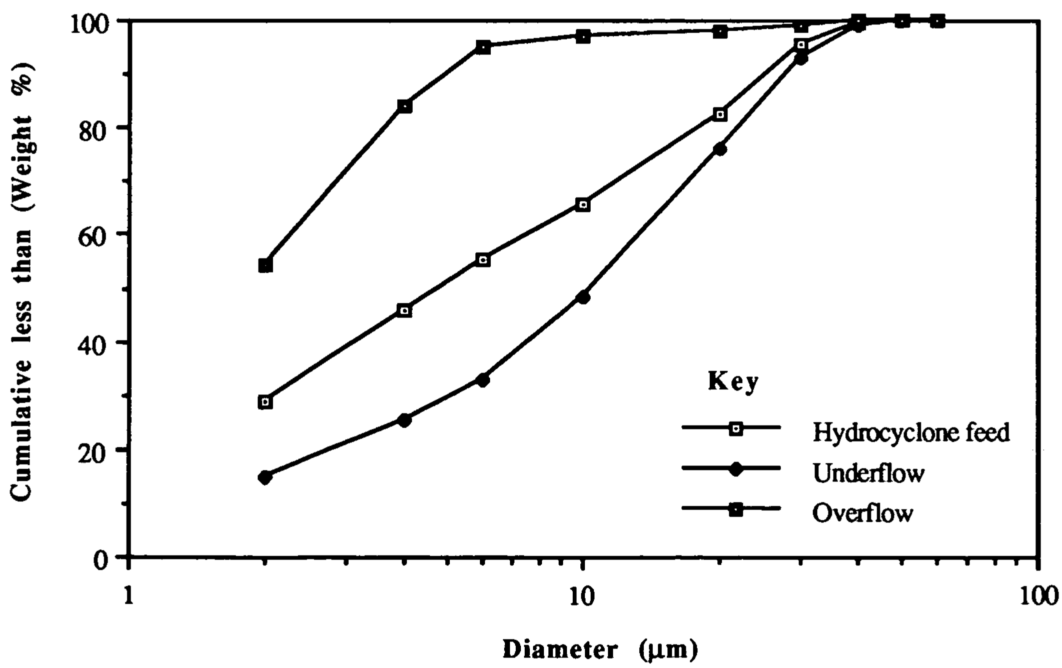

Figure 2. Particle-size distributions of Mutaka kaolinite hydrocyclone products

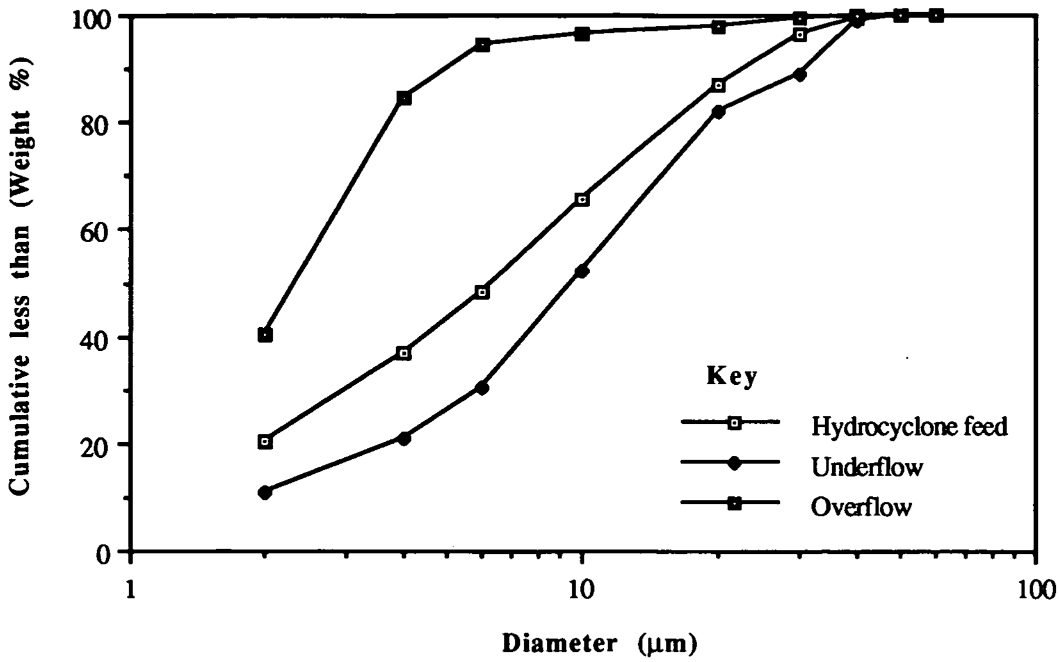

Figure 3. Particle-size distributions of Koki kaolinite hydrocyclone products

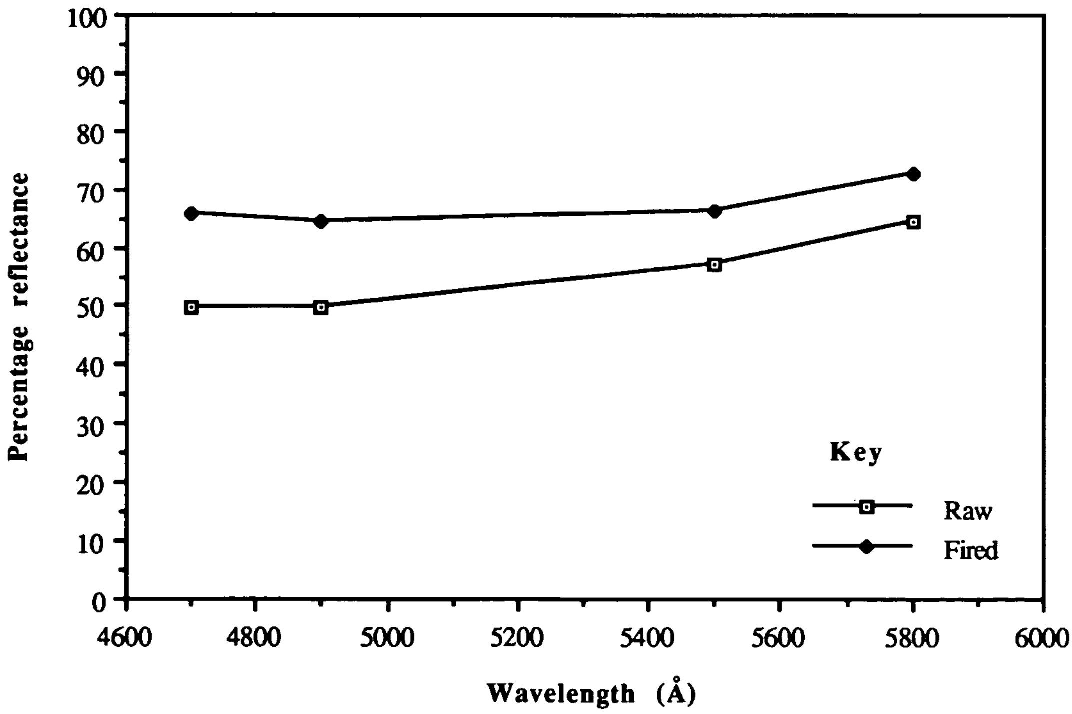

Figure 4. Spectral reflectance curves for Namasera kaolinite overflow product

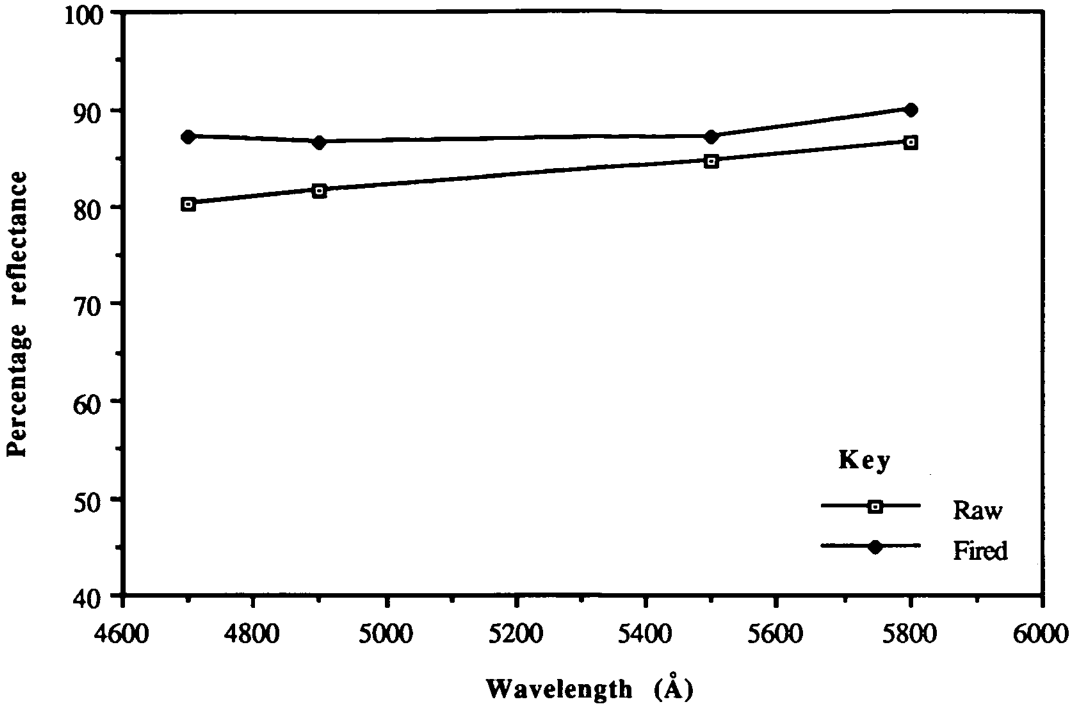

Figure 5. Spectral reflectance curves for Mutaka kaolinite overflow product

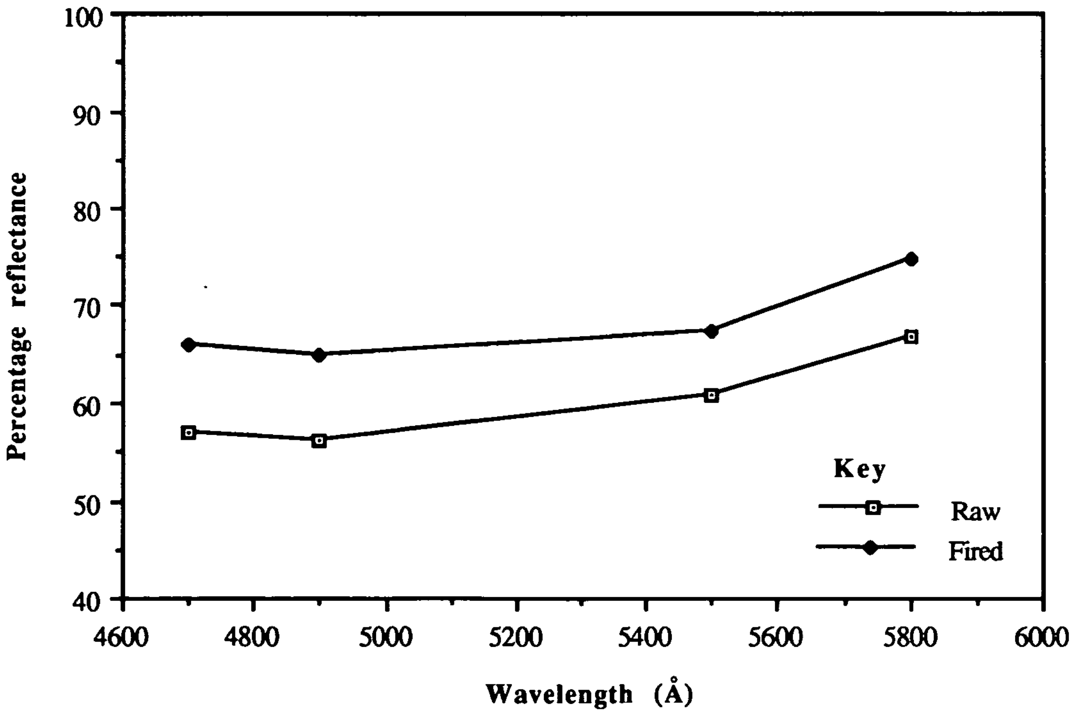

Figure 6. Spectral reflectance curves for Koki kaolinite overflow product

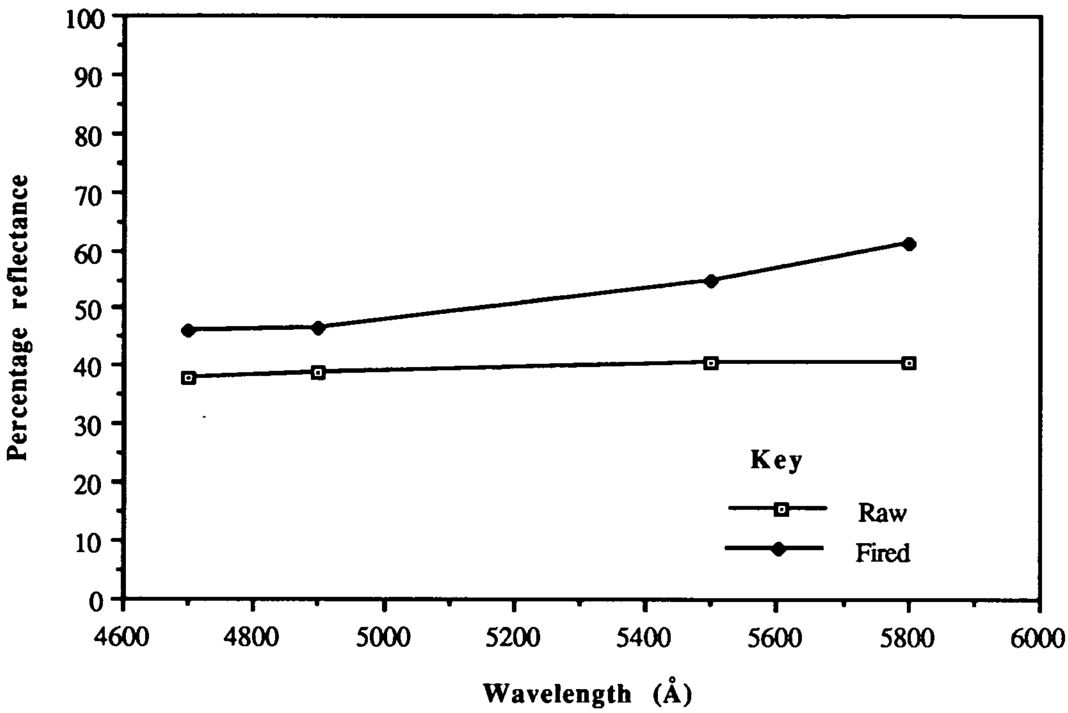

Figure 7. Spectral reflectance curves for Mukona ball clay

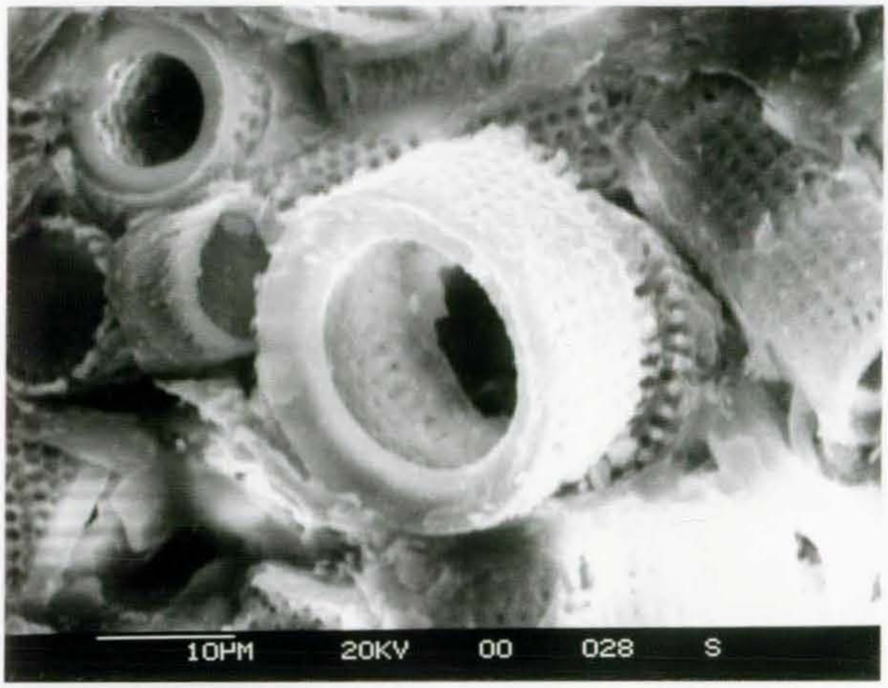

Figure 8. SEM photomicrograph of a single diatom showing its porous tubular nature, Pakwach diatomite, Uganda.

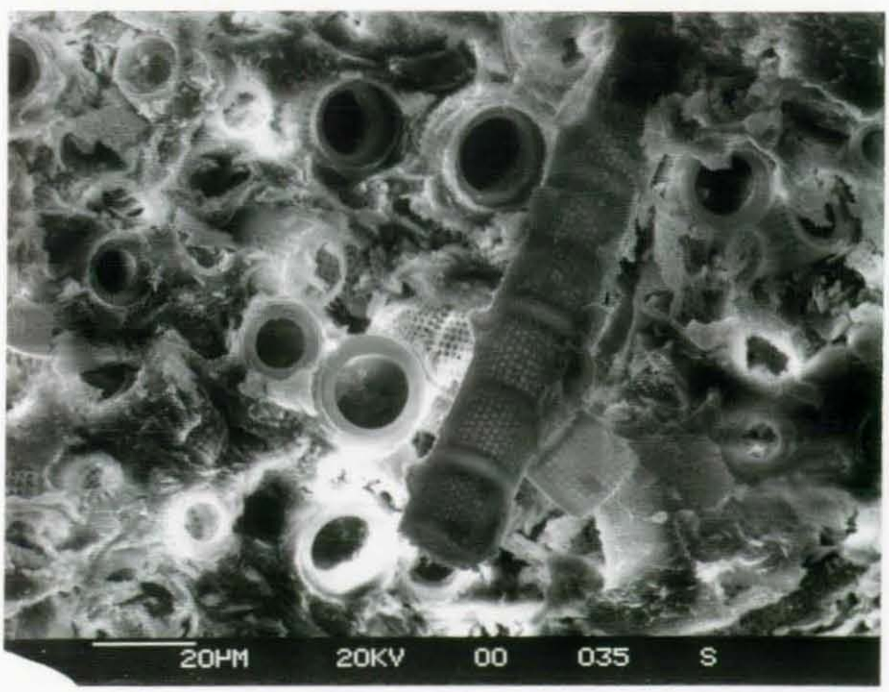

Figure 9. SEM photomicrograph of single diatoms and a chain of diatoms in a matrix of fine grained kaolinite, Pakwach diatomite, Uganda.

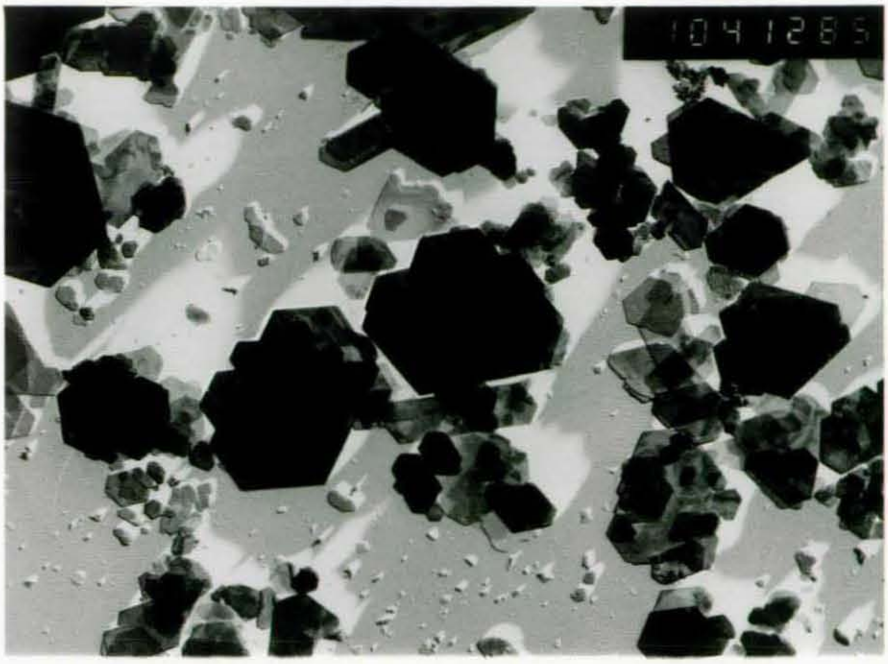

Figure 10. TEM photomicrograph (Mag x 15,500) showing euhedral hexagonal plates and metal shadowing of Namasera kaolinite, Uganda.

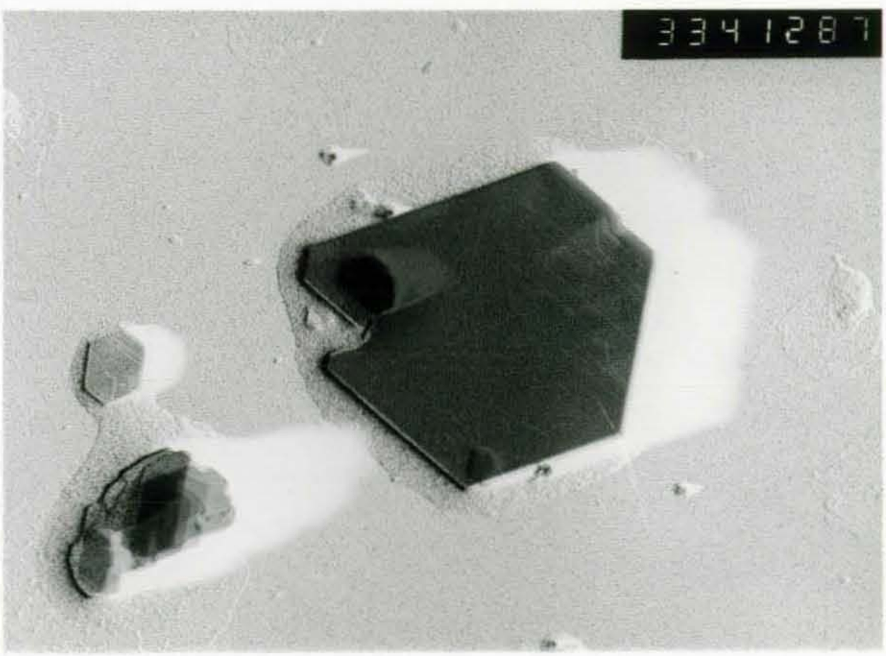

Figure 11. TEM photomicrograph (Mag x 51,500) of a euhedral kaolinite crystal showing visible cleavage and metal shadow, Namasera kaolinite, Uganda.

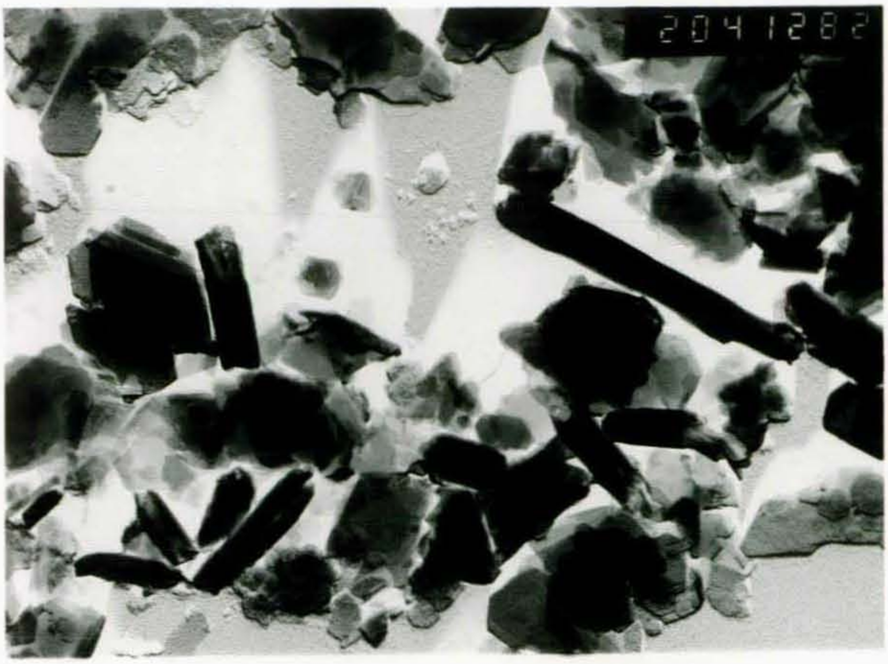

Figure 12. TEM photomicrograph (Mag x 31,000) showing subhedral hexagonal plates and halloysitic rods, Mutaka kaolinite, Uganda.

Figure 13. TEM photomicrograph (Mag x 40,300) showing subhedral and rounded kaolinite plates and halloysitic rods, Mutaka kaolinite, Uganda.

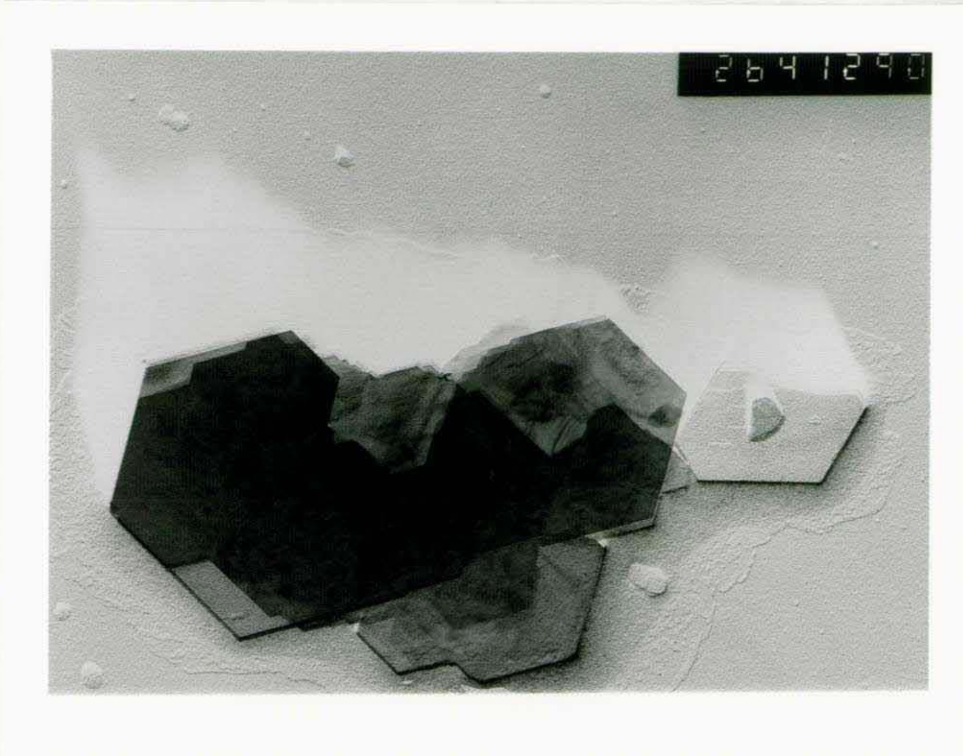

Figure 14. TEM photomicrograph (Mag x 40,300) showing euhedral hexagonal plates with visible cleavage and metal shadowing, Koki kaolinite, Uganda.

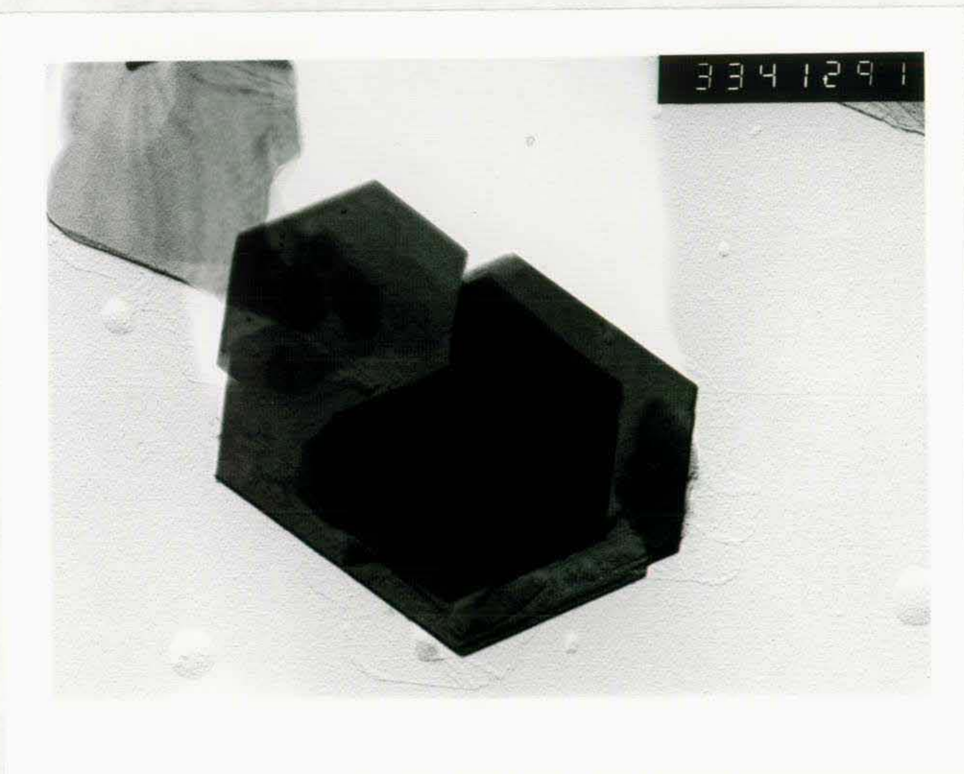

Figure 15. TEM photomicrograph (Mag x 51,500) showing euhedral kaolinite plate, Koki kaolinite, Uganda.