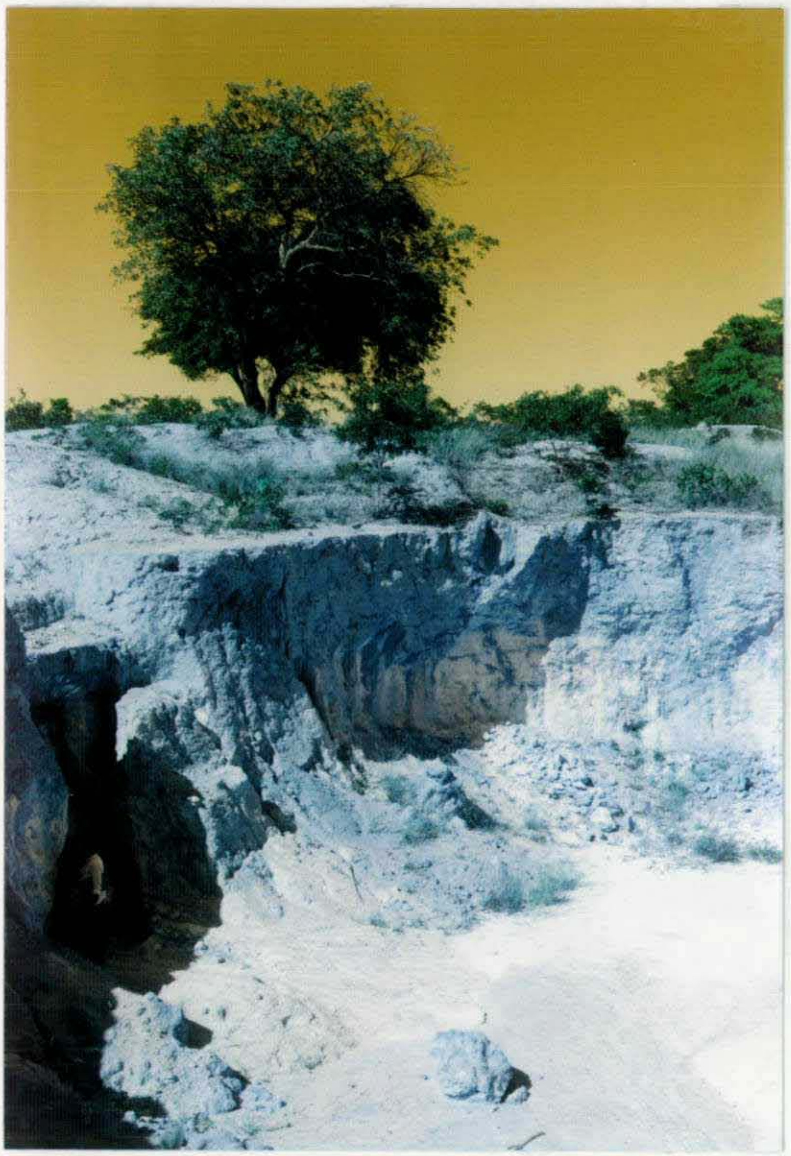
British Geological Survey

TECHNICAL REPORT WG/93/35
Mineralogy and Petrology Series

EVALUATION OF SOME CERAMIC CLAYS FROM ZAMBIA

C J Mitchell



Natural Environment Research Council

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Kaolinised pegmatite with
lateritic overburden exposed
in a quarry near Choma,
Southern Province, Zambia.

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Evaluation of some ceramic clays from Zambia

CJ Mitchell

1. INTRODUCTION

In May 1992 a visit to Zambia was made by CJ Mitchell, Mineralogy & Petrology Group as part of the BGS/ODA project "Minerals for Development" (BGS Technical Report WG/92/19R). This was a follow up to the visits made during 1990 and 1991 and continued the theme of assistance in the development of Zambian industrial mineral resources. During this visit, evaluation of ceramic clays was identified as having an immediate benefit to Zambian industry. This report details the results of a technical evaluation of samples collected during the visit. Three of the samples were assessed as kaolins, two as ball clays and one for use in the production of clay stoves.

Kaolin is a white clay, composed essentially of kaolinite, that is mainly used as a raw material in paper and ceramics. It is also used in paint, rubber, plastic, fertilizers, insecticides and pharmaceuticals. Kaolin is used in ceramics to confer whiteness to the product and therefore fired colour is important. The rheological properties are also important, as these influence the slip casting performance of the clay. A ceramic-grade kaolin should also be fine grained, free of smectite, and low in iron and alkalis. Ball clay is a sedimentary clay, composed mainly of kaolinite, that is used in ceramics, refractories, rubber, plastic, fertilizers and animal feedstuffs. A ball clay should be fine grained, highly plastic, have an off-white to white fired colour, high dry strength, appropriate fired properties and be chemically pure. A clay suitable for the manufacture of ceramic stoves should have high dry strength and appropriate fired properties.

2. SAMPLES

2.1. Choma kaolin

The Choma kaolin occurs approximately 45 km south-east of Choma near Masuku, Southern Province and is situated adjacent to the Maamba colliery railway line (Figure 1). The kaolin occurs as the hydrothermally altered alkali-feldspar component of a cassiterite-bearing pegmatite within the granitic-gneiss basement and has several metres of lateritic overburden. The kaolin lies between 3.5 and 8 metres in depth, with an average grade of 20% kaolinite and estimated resources of 375,000 tonnes (Minex, pers. comm.). Currently the kaolin is worked on demand by consumers such as Moore Pottery who use the kaolin (unprocessed) in the manufacture of their ceramic products. A sample (12kg) was taken for laboratory evaluation.

2.2. Twapia kaolin

The Twapia kaolin occurs approximately 8.5 km south-west of Ndola in the Copperbelt Province and is located at GR 713632 on the 1:100,000 Ndola geological map (Figure 1). The kaolin occurs as a kaolinized-pegmatite at least 6 metres thick within the granitic-gneiss basement and has 2 to 5 metres of lateritic overburden. Nguwo Industrial Mineral Products Ltd supplied a five kg sample of Twapia kaolin to BGS for laboratory evaluation.

2.3. Kapiri Mposhi kaolin

The Kapiri Mposhi kaolin occurs at the Shipungu railway siding 6 km south of Kapiri Mposhi, Central Province and is located on the 1:50,000 topographic map 1428 B1 (Figure 1). The kaolin occurs as a white coloured, arenaceous, quartz-muscovite gneiss with highly kaolinized horizons (Mambwe, 1992 pers. comm.). The sample was collected by Minex, on behalf of Zambia Ceramics Ltd, from a depth of 2 metres and submitted to BGS for laboratory evaluation.

2.4. Ball clay

The Masenche clay occurs at Namakatula within the Masenche stream dambo near Isoka in Northern Province (Figure 1). The dambo is approximately one km wide and the clay is used locally for traditional pottery production. Minex submitted a sample to BGS for laboratory evaluation. The Luela and Misenga clays were both submitted to BGS by Zambia Ceramics Ltd for laboratory evaluation.

2.5. Chikankata clay

Localised deforestation, especially close to urban centres, is a growing problem in Zambia and is partly caused by the production of charcoal for fuel. A potential substitute for charcoal was identified in the form of briquettes made from Maamba Colliery coal fines. A clay stove was designed, to use these briquettes, and it is intended that 10,000 a year will be produced (funded by the Japan International Cooperation Agency). The Chikankata clay was identified as the most promising raw material for this stove and a sample was submitted to BGS by Minex for laboratory evaluation.

The Chikankata clay is situated 5 km south-east of Chikankata Mission in Southern province (Figure 1). The clay is developed as a soil over a pale-green weathered micaceous-gneiss, that contains calcite and quartz with subordinate sericitised andesine, biotite and fine grained anhedral diopside. Occasional prominent bands of marble are present. The gneiss belongs to the Musuma calc-silicate Formation of the Katanga Supergroup (Mambwe, 1993 pers.comm.).

3. METHODS

Mineralogy was determined by X-ray diffraction (XRD), using a Phillips PW 1700 X-ray diffractometer, operating with Co-Kα radiation at 45 kV and 40 mA. Bulk mineralogy was determined on a randomly-oriented powder mount and scanning over the angular range of 3 to 50°2θ. Clay (<2 μm) mineralogy was determined on an oriented mount scanned over the angular range 1.5 to 32 °2θ. The traces were interpreted with reference to the JCPDS database. The kaolinite content of the kaolin samples was determined by thermogravimetric analysis (TG), where the weight losses of samples heated to 1100°C were recorded and interpreted as mineral percentages. The major element chemistry was determined by X-ray fluorescence (XRF) analysis of fused glass discs using a Phillips PW 1480 X-ray fluorescence spectrophotometer.

The particle-size distributions of the samples were determined by wet screening and/or X-ray sedigraph analysis. The brightness, or 'whiteness', of the kaolin samples (unfired and fired to 1180°C) was determined by using a reflectance spectrophotometer and a barium sulphate standard. The viscosity of the kaolin samples was determined using a Brookfield viscometer. Several properties were determined including, flowability (solids content at which a slurry just begins to flow), deflocculant demand, (minimum amount of deflocculant required to obtain minimum viscosity) and viscosity concentration (solids content of a slurry with a viscosity of 5 poise). These rheological properties are important as a kaolin slurry must attain an optimum viscosity at a high solids concentration to enable good slip casting. The plasticity of the ball clay and stove clay samples was determined by the Atterberg testing (liquid and plastic limits). A ball clay must have a high plasticity as this will enable the ceramic body to be 'moulded' and to retain its shape whilst drying.

The Modulus of Rupture (MoR) of the clays was determined by the strength testing of dried test pieces using an Instron model 1011 mechanical testing system. Dry unfired ceramic products must be strong enough to be handled, finished and placed for firing. Fired properties of these clays were determined by temperature gradient firing of 8 test pieces over the range 850°C to 1250°C and measurement of their porosity and volume shrinkage. The change in these properties over the firing range gives a good indication of the degree of vitrification that has occurred in the ceramic body. The formation of glass within the body acts as a cement to produce a relatively dense, strong product. If there is insufficient vitrification the product will be weak. Excessive vitrification will cause distortion due to melting and possibly bloating (rapid expansion caused by the evolution of gas).

Kaolinite concentrates were prepared using a hydrocyclone to separate material into underflow (coarse) and overflow (fine) products (Appendix A). Initial preparation of the kaolin involved attrition scrubbing in water for two hours and wet screening to remove >63 μm material. The hydrocyclone feed was a 5% w/v suspension of the <63 μm fraction. Trials were carried out using a small 15 mm diameter glass hydrocyclone, which gives a cut point of about 10 μm. Kaolinite will concentrate into the fine, or overflow, product and these concentrates were evaluated to determine the potential of the clay for use as a ceramic-grade kaolin.

4. RESULTS AND DISCUSSION

4.1. Choma kaolin

The Choma kaolin is very white and contains dominant quartz, major kaolinite (33%) and minor alkali-feldspar, mica and tourmaline (Table 1 and Figure 2). The hydrocyclone feed (<63 μm fraction) has a high kaolinite grade and recovery of kaolinite from the head, but a low <2 μm content. The 15 mm hydrocyclone trial produced an overflow product with greater kaolinite and <2 μm contents, but with a relatively low recovery of kaolinite from the head (Table 2). Chemical analysis indicates the overflow product to contain a high silica and alumina content and a low titania and iron content relative to the composition of a typical ceramic-grade kaolin (Table 3 and Appendix B). The high brightness of this product was considerably improved by firing (Table 4 and Figure 3). The flowability was 78%, deflocculant demand was 0.45g per 100 g of kaolin and the viscosity concentration was 75% (Figures 4 and 5).

Commercial ceramic-grade kaolins in the UK generally have high kaolinite contents, high <2 μm contents and high fired brightness values. With suitable processing the Choma kaolin can be upgraded to meet these requirements. Wet screening resulted in a product with nearly 80%

kaolinite and hydrocycloning upgraded this to a product containing nearly 90% kaolinite. The Choma kaolin is currently used as an unprocessed raw material in the production of ceramics. Processing (wet screening and hydrocycloning) would upgrade the kaolin and improve its quality for use as a ceramic raw material.

4.2. Twapia kaolin

The Twapia kaolin is pale yellowish brown to off white in colour and consists of friable lumps of fine grained material. The kaolin contains dominant quartz, major kaolinite (36%) and mica, minor alkali-feldspar and trace tourmaline (Table 1). Kaolinite grade, and recovery of kaolinite from the head to the <63 μm fraction were reasonably high, although the percentage of material <2 μm was relatively low. The 15 mm hydrocyclone separation produced an overflow with a greater kaolinite grade and <2 μm content, but with a low kaolinite recovery (Table 2). Chemical analysis indicates it to contain a high silica and alumina content and a high titania and iron content relative to a typical ceramic-grade kaolin (Table 3 and Appendix B). This product had a low unfired brightness which was not significantly improved by firing (Table 4 and Figure 6).

The Twapia kaolin could not be upgraded in the laboratory to meet specifications for ceramic-grade kaolin. Hydrocycloning produced a material which was sufficiently fine, but with a low kaolinite content and low fired brightness values.

4.3. Kapiri Mposhi kaolin

The Kapiri Mposhi kaolin contains dominant quartz, major kaolinite (32%) and alkali-feldspar and minor mica (Table 1). The hydrocyclone feed (<63 μm fraction) had a high kaolinite grade and recovery and a high <2 μm content. The 15 mm hydrocyclone separation produced an overflow product with a high kaolinite grade and a very high <2 μm content, although kaolinite recovery from the head was low (Table 2). Chemical analysis indicates it to contain a high silica and alumina content and a high titania and iron content relative to typical ceramic-grade kaolin (Table 3 and Appendix B). This product had a low unfired brightness which was not improved by firing (Table 4 and Figure 7).

The Kapiri Mposhi kaolin could not be upgraded to meet ceramic-grade requirements. Hydrocycloning produced a very fine-grained material with a high kaolinite content, but the fired brightness values were too low.

4.4. Masenche clay

The Masenche clay is grey in colour and contains dominant quartz, major kaolinite, minor alkali-feldspar and a trace of mica and smectite (Table 1 and Figure 8). Chemical analysis indicates it to contain a high silica and iron content and low alumina and alkalis content relative to the composition of a typical commercial ball clay (Table 3 and Appendix C). Based on its particle-size distribution the clay is classified as a sandy silty clay (Table 5 and Appendix D). The clay has a low plasticity and does not plot in the acceptable moulding properties envelope of Figure 9. The fired colour of the clay is orange brown. The vitrification curve for the Masenche clay shows it to be an "open firing", or 'refractory', clay, in that there is little change in properties over the fired temperature range. Porosity falls only gradually with firing, whereas the shrinkage gradually increases (Figure 10). Any ceramic body formed from this material and fired at these temperatures is likely to be of relatively low strength.

Commercial ball clays in the UK generally have a high <2 μm content, high fired brightness values and moderately high plasticity. They contain varying quantities of kaolinite, quartz, mica and organic matter. Although the Masenche clay has a high <2 μm content, its low plasticity and poor fired colour preclude its use as a ball clay.

4.5. Luela clay

The Luela clay is light greyish brown in colour and contains dominant quartz, major kaolinite, minor alkali-feldspar and a trace of mica and smectite (Table 1). Chemical analysis indicates it has a high silica and iron content and a low alumina and alkalis content relative to a typical commercial ball clay (Table 3 and Appendix C). Based on its particle-size distribution the clay is classified as a sandy silty clay (Table 5 and Appendix D). The clay has a low plasticity and plots in the optimum moulding properties envelope for ceramic clay (Figure 9). The fired colour is light brown. The vitrification curve for the Luela clay shows it also to be an "open firing", or refractory, clay with a relatively high porosity that falls only gradually with firing, together with a gradual increase in shrinkage (Figure 11). Any ceramic body formed from this material and fired at these temperatures is likely to be of relatively low strength. The relatively coarse particle-size and poor fired colour preclude the use of this material as a ball clay.

4.6. Misenga clay

The Misenga clay is dark grey in colour and contains dominant quartz, major kaolinite and alkali-feldspar, minor mica and trace smectite (Table 1). Chemical analysis indicates it to contain a relatively low silica and alumina content and a high iron content relative to a typical commercial ball clay (Table 3 and Appendix C). Based on its particle-size distribution the clay is classified as a silty clay (Table 5 and Appendix D). The clay has a low plasticity and does not plot in the acceptable moulding properties envelope of Figure 9. The fired colour is light orange brown. The vitrification curve for the Misenga clay shows the porosity to fall sharply with firing, from 35% at 950°C to 2% at 1100°C and the shrinkage values increase sharply with firing (Figure 12). This behaviour indicates that substantial vitrification has taken place and that a relatively strong, dense ceramic body has formed. The poor fired colour of this clay precludes irs use as a ball clay.

These three clays (Masenche, Luela and Misenga) could be used to make craft pottery or structural products such as bricks and tiles. The properties of each individual clay could be modified by blending in the other clays. For example blending the Misenga and Luela clays together would produce a clay with adequate moulding and fired properties for use in bricks and pottery.

4.7. Chikankata clay

The Chikankata clay consists of dark reddish brown lumps with a micaceous sheen. The clay contains dominant talc, major quartz and smectite, minor tremolite and a trace of feldspar and kaolinite (Table 1 and Figure 13). The chemical analysis is given in Table 3. Based on its particle-size distribution the clay is classified as a silty clay sand (Table 5 and Appendix D). The clay has a low plasticity and plots in the acceptable moulding properties envelope of Figure 9. The modulus of rupture (MoR) is 10.3 kg/cm^2. The fired colour of the clay is reddish brown. The vitrification curve shows the porosity to decrease and shrinkage to increase with an increase in firing temperature. Above 1150°C the clay bloated (Figure 14). This indicates that adequate vitrification has occurred before the clay bloats and that a ceramic body formed below 1100°C would be of relatively high strength.

The Chikankata clay has acceptable moulding properties, moderate dry strength and adequate fired properties. The clay appears to be a suitable raw material for the production of clay stoves. However, it is recommended that further ceramic property testing is performed, such as fired compressive and impact strength, resistance to thermal shock and durability before any final decision is made as to its suitability.

5. CONCLUSIONS

1. The Choma kaolin is an excellent potential source of ceramic-grade kaolin. It is relatively easy to process to produce the requisite kaolinite-grade, colour and particle-size distribution. The Twapia and Kapiri Mposhi kaolins do not meet the requirements for ceramic-grade kaolin, chiefly because of their poor fired colour.

2. Poor fired colour precludes the use of the Masenche, Luela and Misenga clays as ball clays in whiteware ceramics. However, these clays are probably suitable (in raw and / or blended form) as raw material for craft pottery or structural clay products such as bricks and tiles.

3. The Chikankata clay has acceptable moulding properties, moderate dry strength and adequate fired properties for use as a raw material for the production of clay stoves. However, it is recommended that further ceramic property testing is performed before any final decision is made as to its suitability.

6. REFERENCES

Bain, JA and Highley, DE (1979) Regional appraisal of clay resources - a challenge to the clay mineralogist. *Proc. Int. Clay Conf.* 1978, Oxford, pp 437-446.

Bloodworth, AJ, Highley, DE and Mitchell, CJ (1993) Kaolin - Industrial Minerals Laboratory Manual. *British Geological Survey, Tech. Rept.* **WG/93/1**.

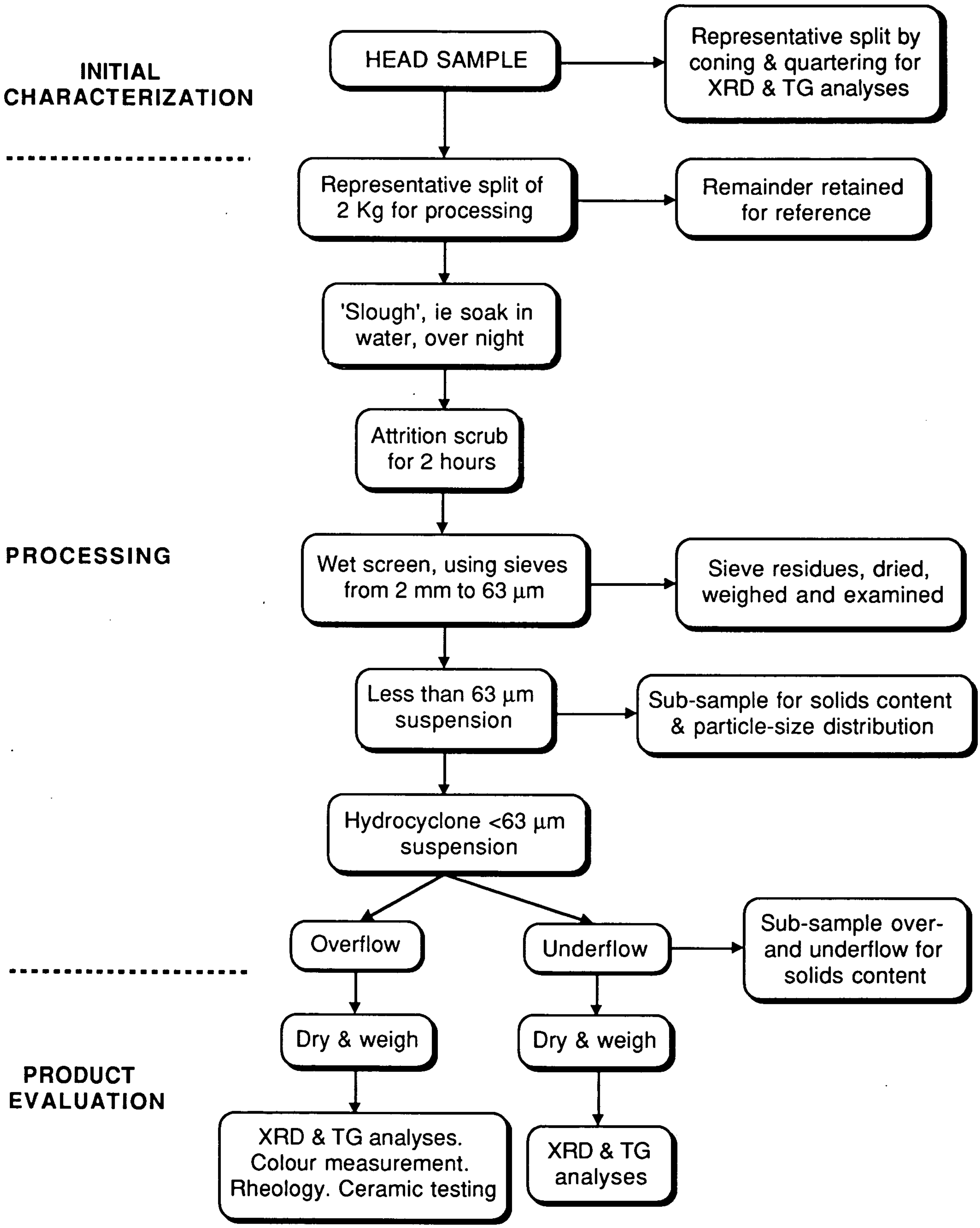
Highley, DE (1975) Ball Clay - Mineral Dossier No.11. Mineral Resources Consultative Committee, HMSO.

Mitchell, CJ (1992) Visit to Zambia and Zimbabwe, 12 May - 30 May 1992. *British Geological Survey, Tech. Rept.* **WG/92/19R**.

Selley, RC (1982) An introduction to sedimentology. Academic Press, 2nd edition.

WBB (1991) Clays - Summary of technical data (WBB Group ceramic range). WBB Group Worldwide.

Appendix A. Flowchart for the processing of kaolin-bearing samples



Appendix B. Ceramic-grade kaolin specifications

	(a)	(b)	(c)
SiO_2	47	48	48
TiO_2	0.03	0.02	0.05
Al_2O_3	38	37	37
Fe_2O_3	0.39	0.70	1.00
MgO	0.22	0.30	0.30
CaO	0.10	0.06	0.07
Na_2O	0.15	0.10	0.10
K_2O	0.80	1.85	2.00
LOI	13.0	12.2	12.1
% kaolinite	93	81	83
% micaceous material	4	15	13
% feldspar	1	1	2
% other minerals	2	3	2
% <2 μm	85	57	40
% >10 μm	1	10	20
Modulus of rupture (Kgf/cm^2) [1]	55.0	25.7	11.0
Casting concentration [2]	58.0	62.5	64.5
Deflocculant demand [3]	1.5	0.65	0.55
Casting rate (mm^2/min)	0.35	0.80	1.5
% Brightness (1180°C) [4]	95	86	82
% Shrinkage (1180°C)	10	9	7.5

(a) ECC Super Standard Porcelain; high quality tableware, porcelain and bone china.

(b) ECC Grolleg; Earthenware, tableware.

(c) ECC Remblend; Sanitaryware.

1: Dried at 110°C. 2: Weight percent solids content required for a viscosity of 5 poise.

3: Amount of P84 sodium silicate required to produce viscosity equilibrium. 4: At 457 nm wavelength.

(After Bloodworth et al, 1993)

Appendix C. Commercial ball clay specifications

	(a)	(b)	(c)
SiO_2	50	56.8	68
TiO_2	1	1.3	1.5
Al_2O_3	32.9	27.5	21.3
Fe_2O_3	1.2	1	0.8
MgO	0.3	0.3	0.3
CaO	0.2	0.2	0.1
Na_2O	0.2	0.3	0.4
K_2O	1.6	2.2	2.3
LOI	12.6	9.5	5.5
C	1.6	1.8	0.1
% <2 μm	86	73	55
% >10 μm	2	5	13
Modulus of rupture (MN/m^2) [1]	5.9	7.8	4.1
Deflocculant requirement [2]	0.4	0.1	0.3
% Brightness (1120°C) [3]	77	65	66
% Linear shrinkage (1120°C)	9	7	4

	(d)	(e)	(f)
% kaolinite	33-68	20-90	20-83
% quartz	15-48	0-60	5-60
% mica	0-22	0-40	0-30
% organic matter	0-3	0-16	0-8

(a) WBB Standard ball clay blend SKD

(b) WBB Refined ball clay Sanblend 90

(c) WBB Ball clay group 4 CDL

(d) Petrockstow basin ball clay mineralogy

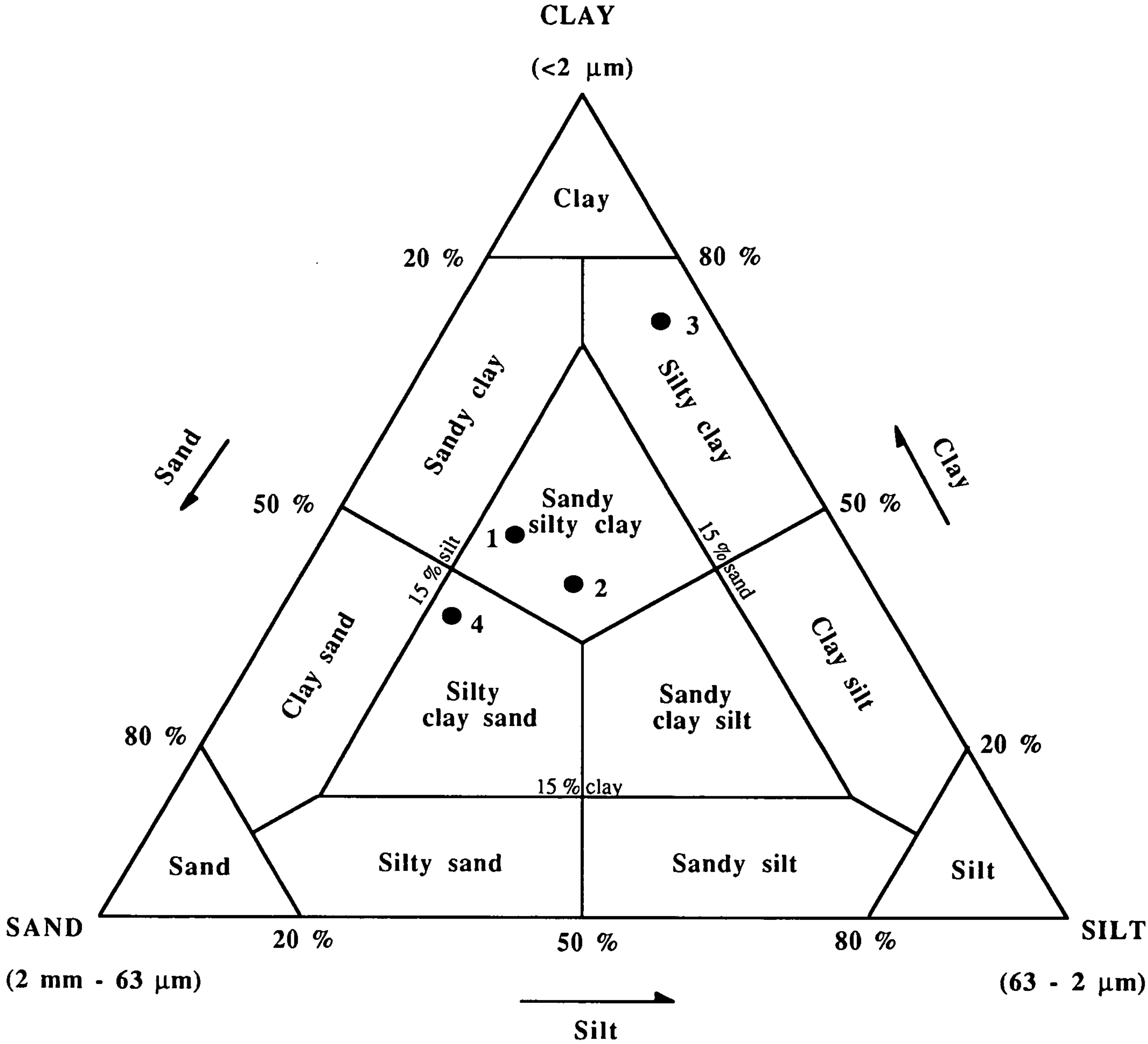
(e) Bovey basin ball clay mineralogy

(f) Dorset ball clay mineralogy

1: Dried at 110°C. 2: Amount of 3:1 sodium silicate:sodium carbonate required to produce viscosity of 5 poise.
3: At 464 nm wavelength.

(After Highley, 1975 and WBB, 1991)

Appendix D. Unconsolidated sediment grain-size classification.
(after Selley, 1982)



Key : 1 Masenche clay
2 Luela clay
3 Misenga clay
4 Chikankata clay

Table 1. Mineralogy of ceramic clay from Zambia.

Sample	Mineralogy
Choma kaolin	Quartz ****, kaolinite 33%, alkali feldspar **, mica ** and tourmaline **.
Twapia kaolin	Quartz ****, kaolinite 36%, mica ***, alkali feldspar ** and tourmaline *.
Kapiri Mposhi kaolin	Quartz ****, kaolinite 32%, alkali feldspar *** and mica **.
Masenche clay	Quartz ****, kaolinite ***, alkali feldspar **, mica * and smectite *.
Luela clay	Quartz ****, kaolinite ***, alkali feldspar **, mica * and smectite *.
Misenga clay	Quartz ****, kaolinite ***, alkali feldspar ***, mica ** and smectite *.
Chikankata clay	Talc ****, quartz ***, smectite ***, tremolite **, feldspar * and kaolinite *.
Kafwimbi clay	Quartz ****, kaolinite ***, mica * and feldspar *.
Chama clay	Quartz, kaolinite **, smectite ** and feldspar *.

N.B. The semi-quantitative mineralogy was determined by X-ray diffraction and binocular microscope. The kaolinite contents were determined by thermogravimetric analysis. The semi-quantitative ranking is as follows: **** = Dominant, *** = Major, ** = Minor and * = Trace.

Table 2. Grade and recovery figures for processing of kaolin from Zambia.

Product	Kaolinite		Particle-size	
	Grade (wt %)	Recovery (wt %)	<10 µm (wt %)	<2 µm (wt %)
Choma kaolin				
Head	33	100	16	5
Hydrocyclone feed (<63 µm)	78	70	52	15
Underflow	75	52	38	4
Overflow	88	18	96	49
Twapia kaolin				
Head	36	100	24	7
Hydrocyclone feed (<63 µm)	59	67	59	17
Underflow	55	50	51	8
Overflow	76	17	97	57
Kapiri Mposhi kaolin				
Head	32	100	15	11
Hydrocyclone feed (<63 µm)	83	56	71	50
Underflow	80	32	59	28
Overflow	88	24	98	85

N.B. Recovery figures refer to amount of kaolinite recovered from head into product. All products from 15 mm hydrocyclone separation.

Table 3. Chemistry of ceramic clay from Zambia.

	Choma kaolin (wt %)	Twapia kaolin (wt %)	Kapiri Mpsohi kaolin (wt %)	Masenche clay (wt %)	Luela clay (wt %)	Misenga clay (wt %)	Chikankata clay (wt %)
SiO_2	45.62	45.28	43.54	75.88	65.74	53.04	53.42
TiO_2	0.01	0.21	0.34	0.89	2.03	1.17	0.65
Al_2O_3	38.54	35.97	36.37	11.84	18.59	25.72	10.42
$Fe_2O_3^t$	0.18	2.23	1.74	3.55	3.49	5.16	8.45
MnO	0.00	0.00	0.01	0.02	0.01	0.01	0.09
MgO	0.06	0.44	0.18	0.21	0.55	0.82	15.22
CaO	0.12	0.16	0.28	0.14	0.27	0.29	2.09
Na_2O	0.13	0.11	0.21	0.18	0.12	0.18	0.52
K_2O	0.66	1.04	0.54	0.74	0.69	1.92	0.20
P_2O_5	0.03	0.02	0.03	0.03	0.02	0.03	0.08
LOI	14.04	13.09	14.21	5.78	7.60	10.70	8.18
Total	99.39	98.55	97.45	99.26	99.11	99.04	99.32

N.B. The kaolin samples are the overflow products from 15 mm hydrocyclone separation.

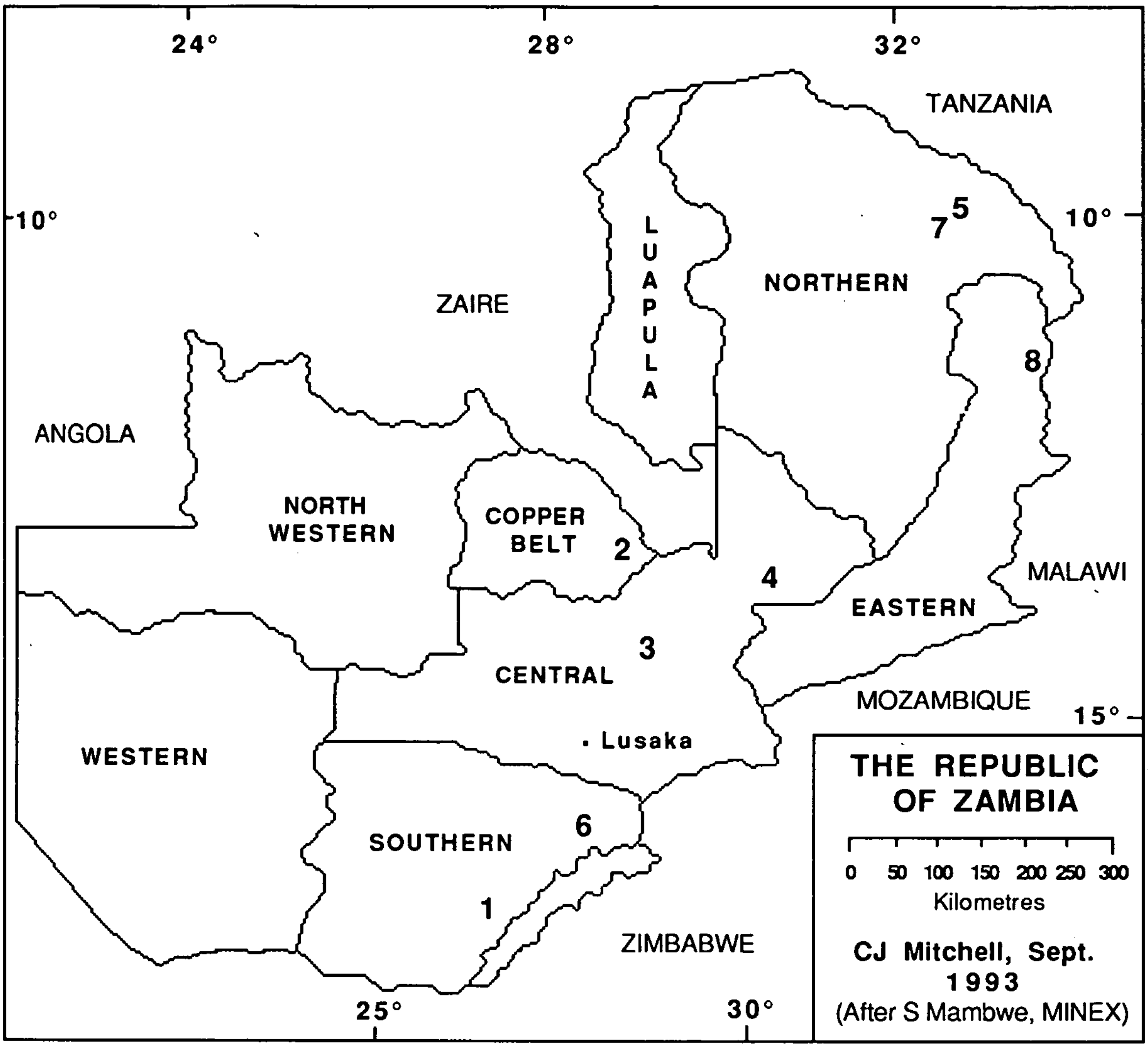
Table 4. Brightness values for processed kaolin from Zambia.

Wavelength (Å)	Choma Unfired	Choma Fired	Twapia Unfired	Twapia Fired	Kapiri Mposhi Unfired	Kapiri Mposhi Fired
4260 (601)	81.7	95.3	59.2	74.3	69.9	70.2
4700 (602)	82.6	93.7	64.5	75.8	71.7	70.9
4900 (603)	82.5	92.8	64.4	76.0	71.5	71.5
5200 (604)	83.1	95.4	66.4	79.0	72.5	74.4
5500 (605)	86.8	93.1	74.4	80.3	76.7	76.1
5800 (606)	89.1	93.4	81.0	82.7	78.3	77.5
6000 (607)	92.1	94.0	87.2	84.8	81.5	80.4
6600 (608)	91.3	94.4	88.7	86.2	83.1	79.6
6840 (609)	91.5	94.6	88.7	85.6	82.7	79.8

N.B. The brightness values are percentage reflectance as determined using a reflectance spectrophotometer and a barium sulphate calibration standard. The figures in brackets are the filter wheel numbers.

Table 5. Particle-size distribution and plasticity of selected clay samples from Zambia

Sample	Sand (>63 µm) (wt %)	Silt (63 to 2 µm) (wt %)	Clay (<2 µm) (wt %)	Total (wt %)	Plastic limit (wt %)	Liquid limit (wt %)	Plasticity index (wt %)
Masenche clay	32	20	48	100	17	73	56
Luela clay	31	28	41	100	23	52	29
Misenga clay	3	29	68	100	22	74	52
Chikankata clay	46	17	37	100	26	39	13



Key :	
1 Choma kaolin	5 Masenche clay
2 Twapia kaolin	6 Chikankata clay
3 Kapiri Mposhi kaolin	7 Kafwimbi clay
4 Chilulwe kaolin	8 Chama clay

Figure 1. Location of industrial minerals from Zambia.

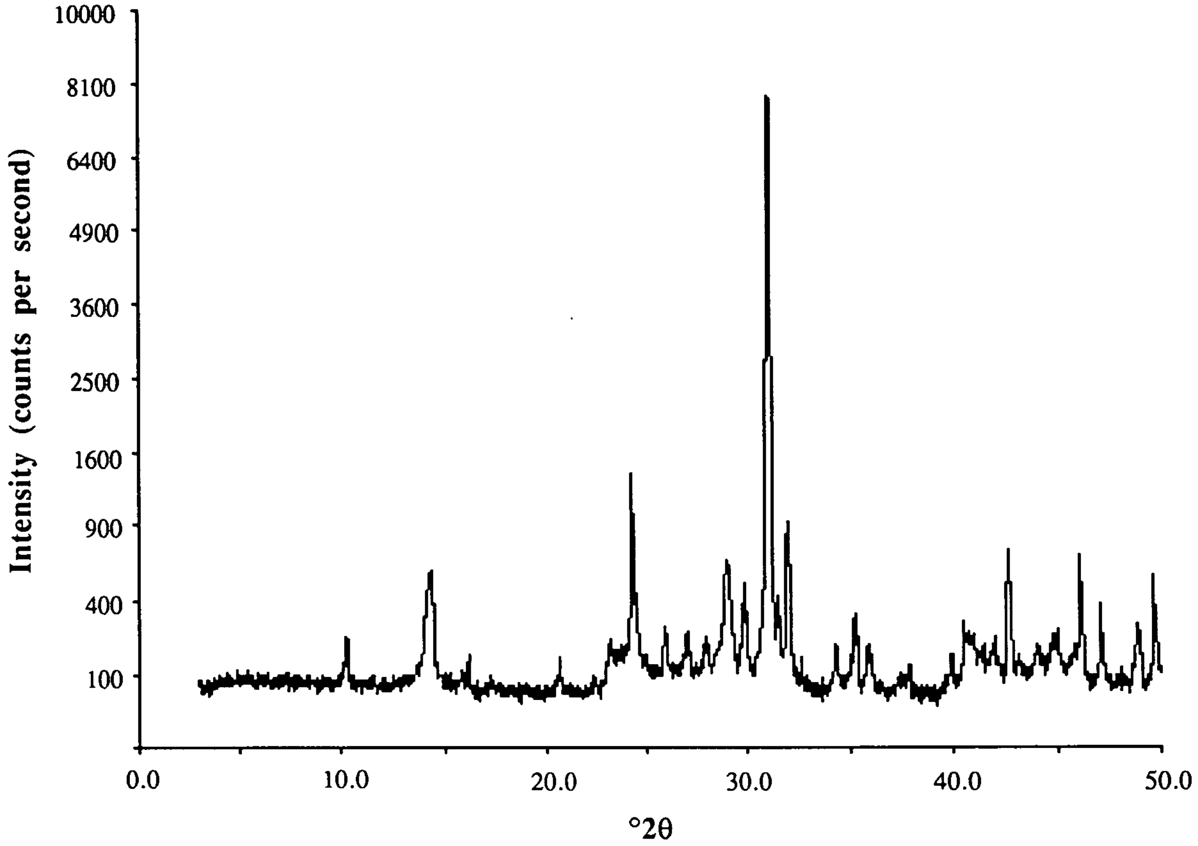


Figure 2. X-ray diffraction trace of Choma kaolin, Southern Province, Zambia.

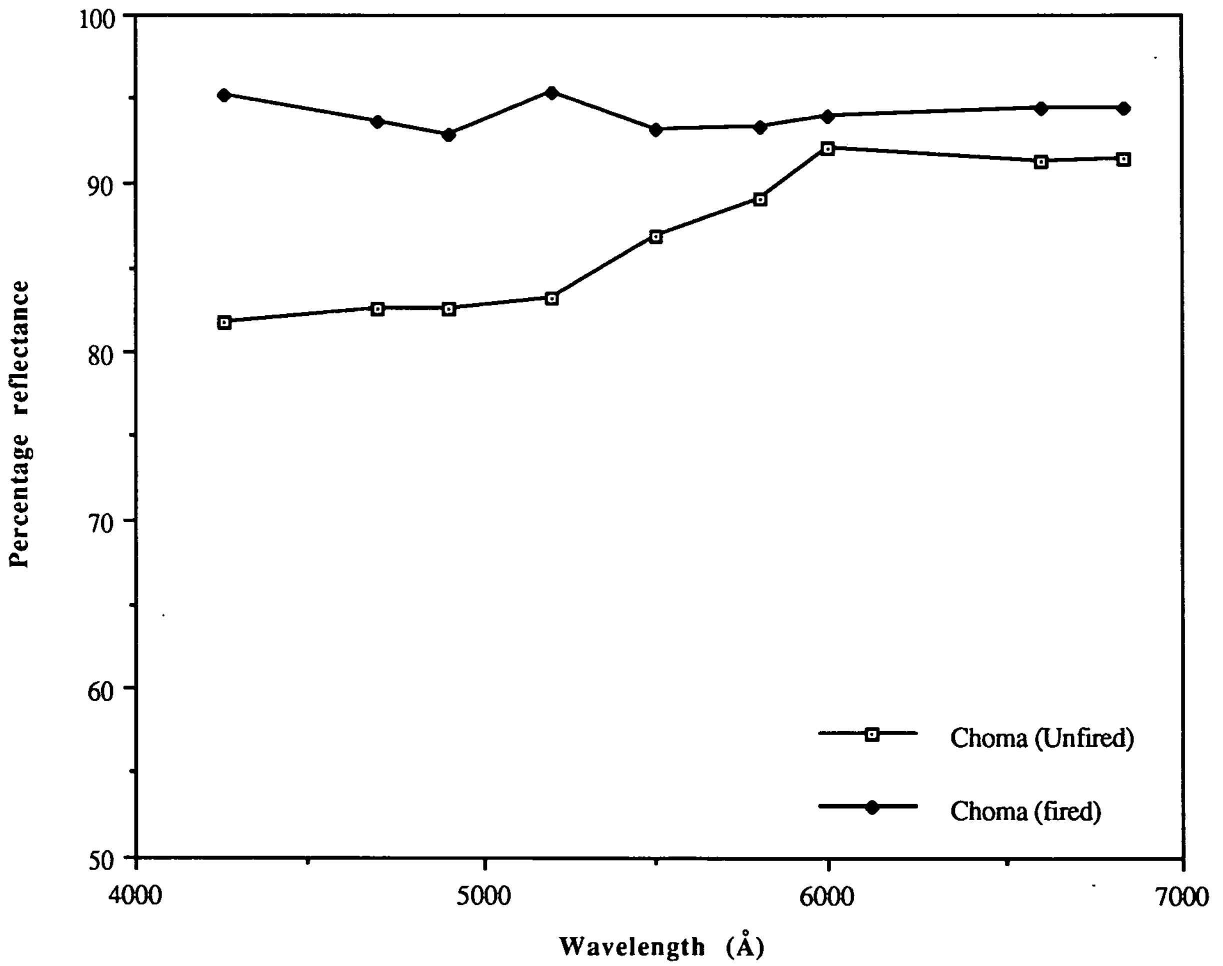


Figure 3. Spectral reflectance curve for Choma kaolin, Southern Province, Zambia.

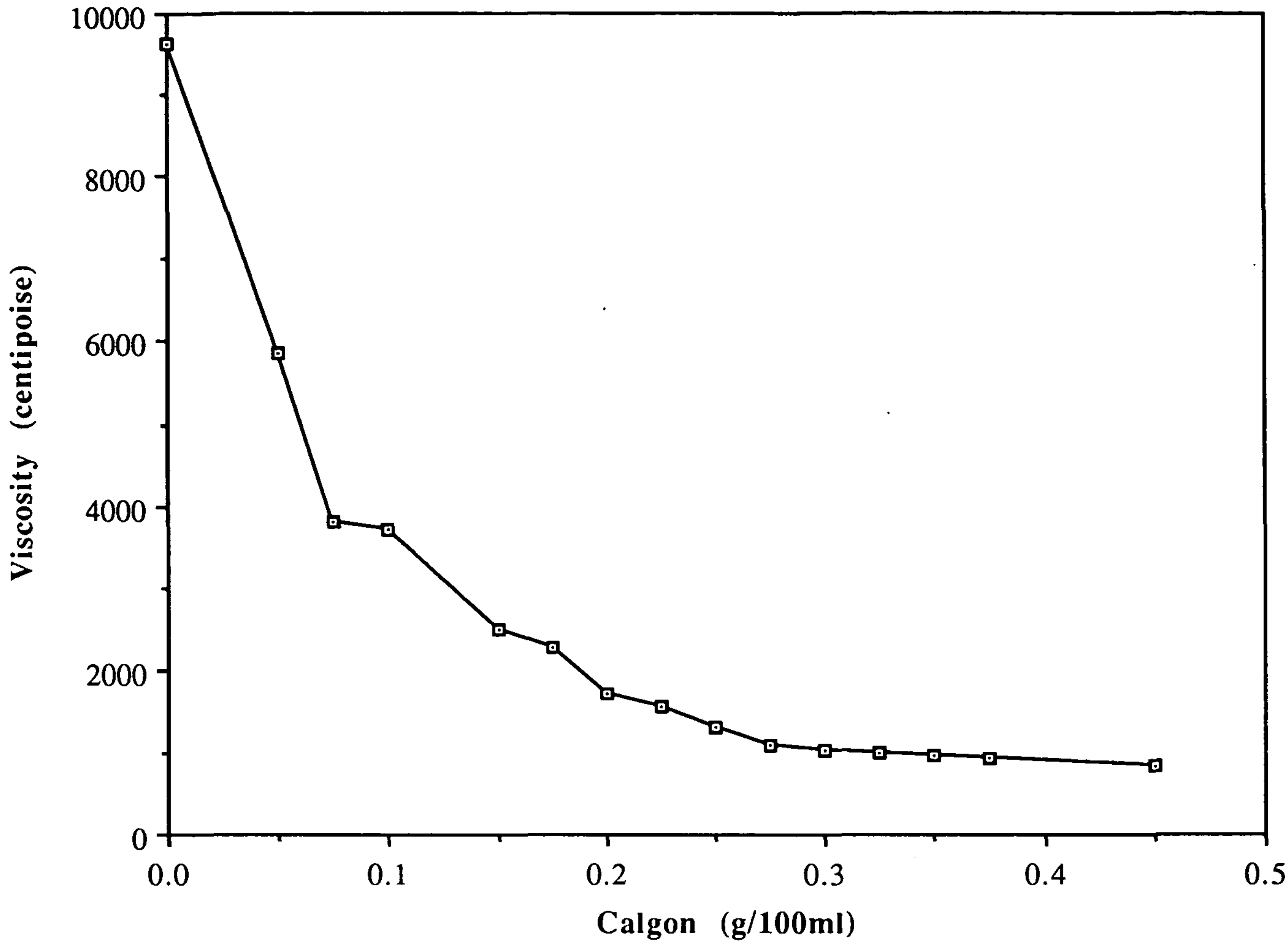


Figure 4. Deflocculant demand of Choma kaolin, Southern Province, Zambia.

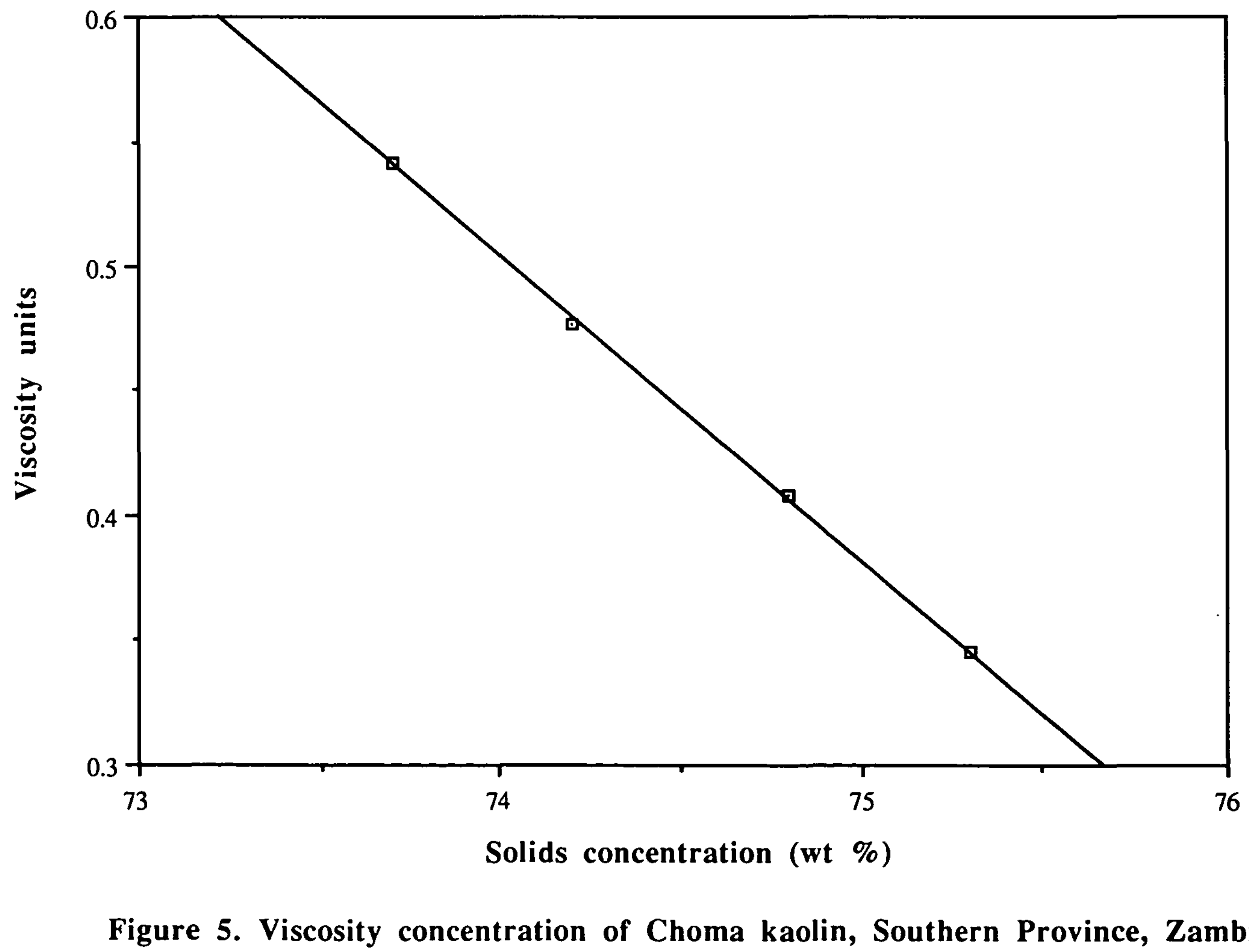


Figure 5. Viscosity concentration of Choma kaolin, Southern Province, Zambia.

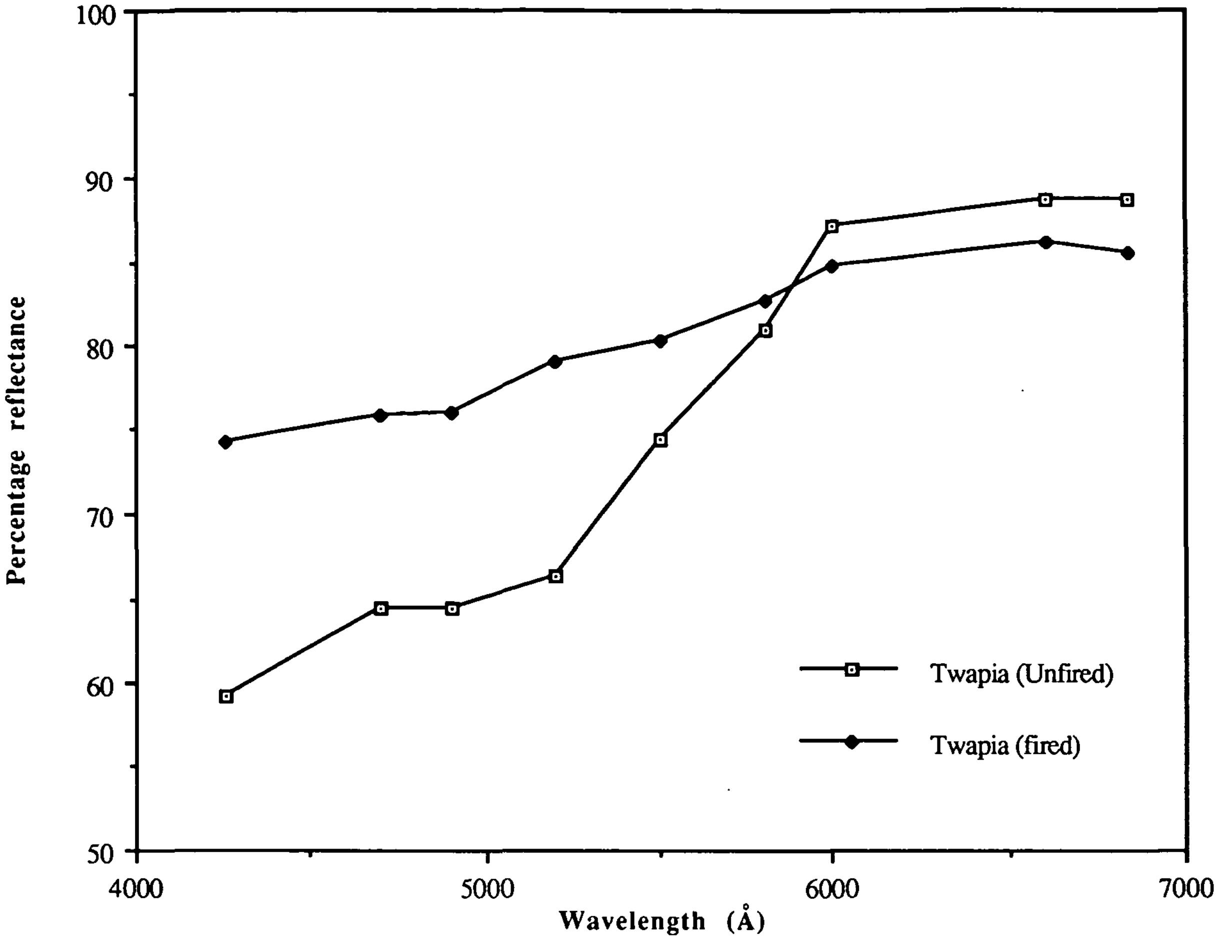


Figure 6. Spectral reflectance curve for Twapia kaolin, Copperbelt Province, Zambia.

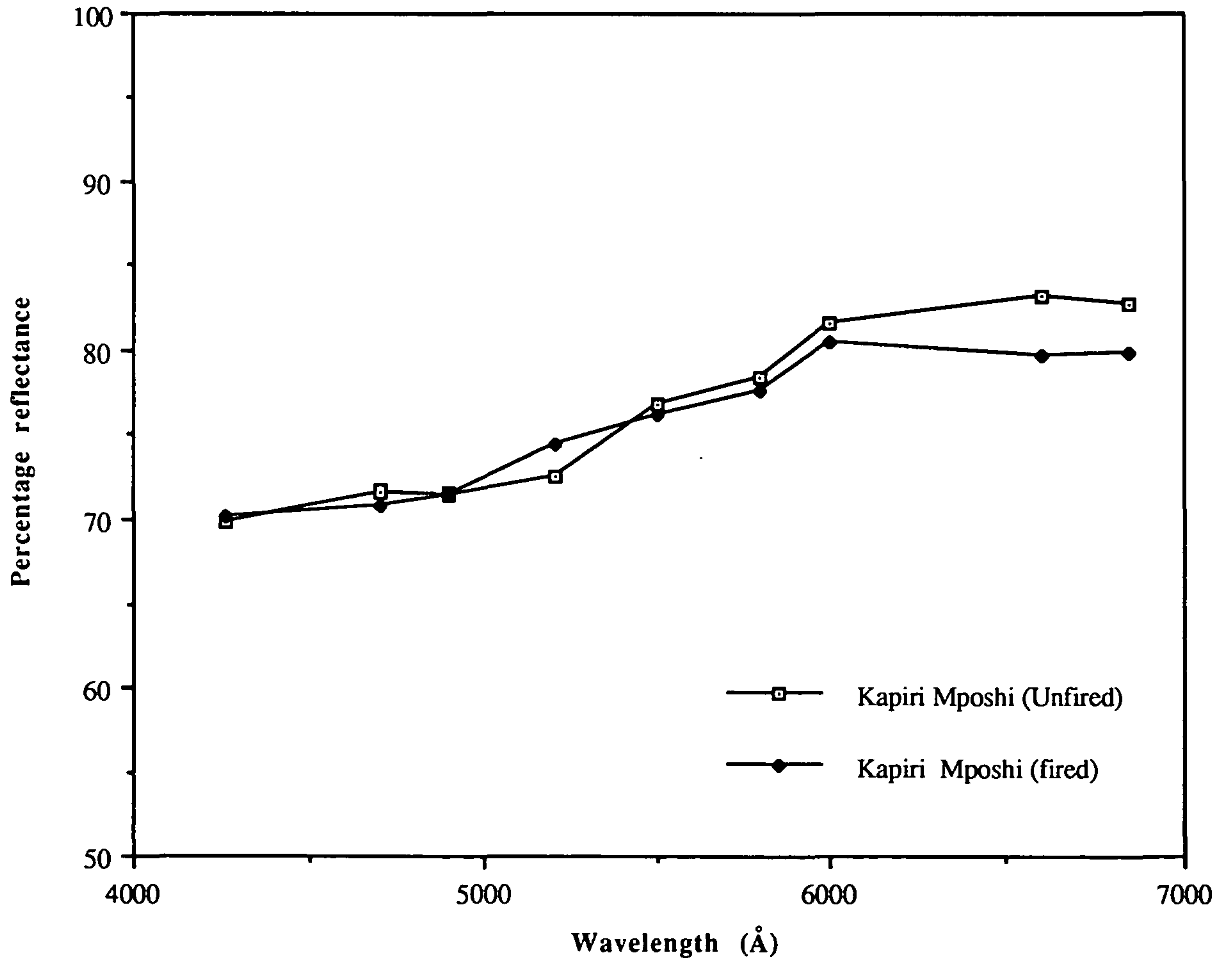


Figure 7. Spectral reflectance curve for Kapiri Mposhi kaolin, Central Province, Zambia

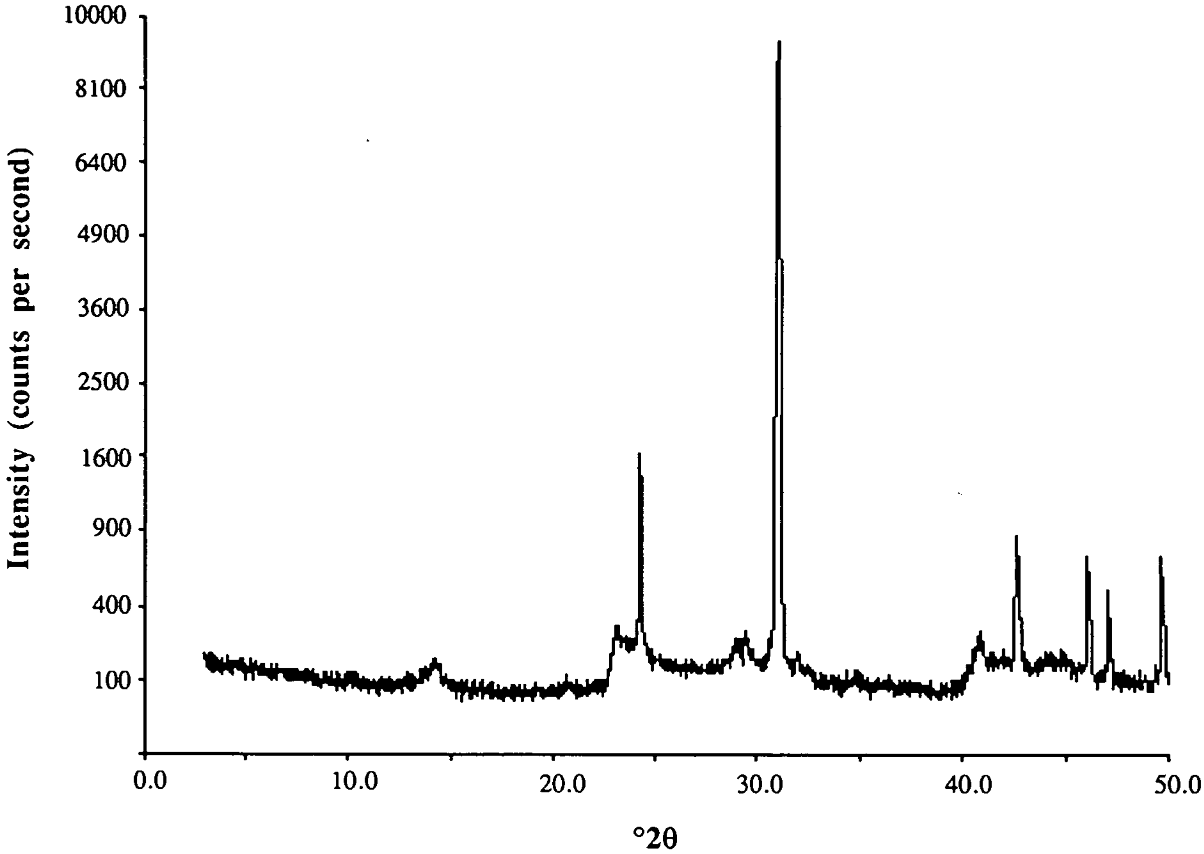


Figure 8. X-ray diffraction trace of Masenche clay, Northern Province, Zambia.

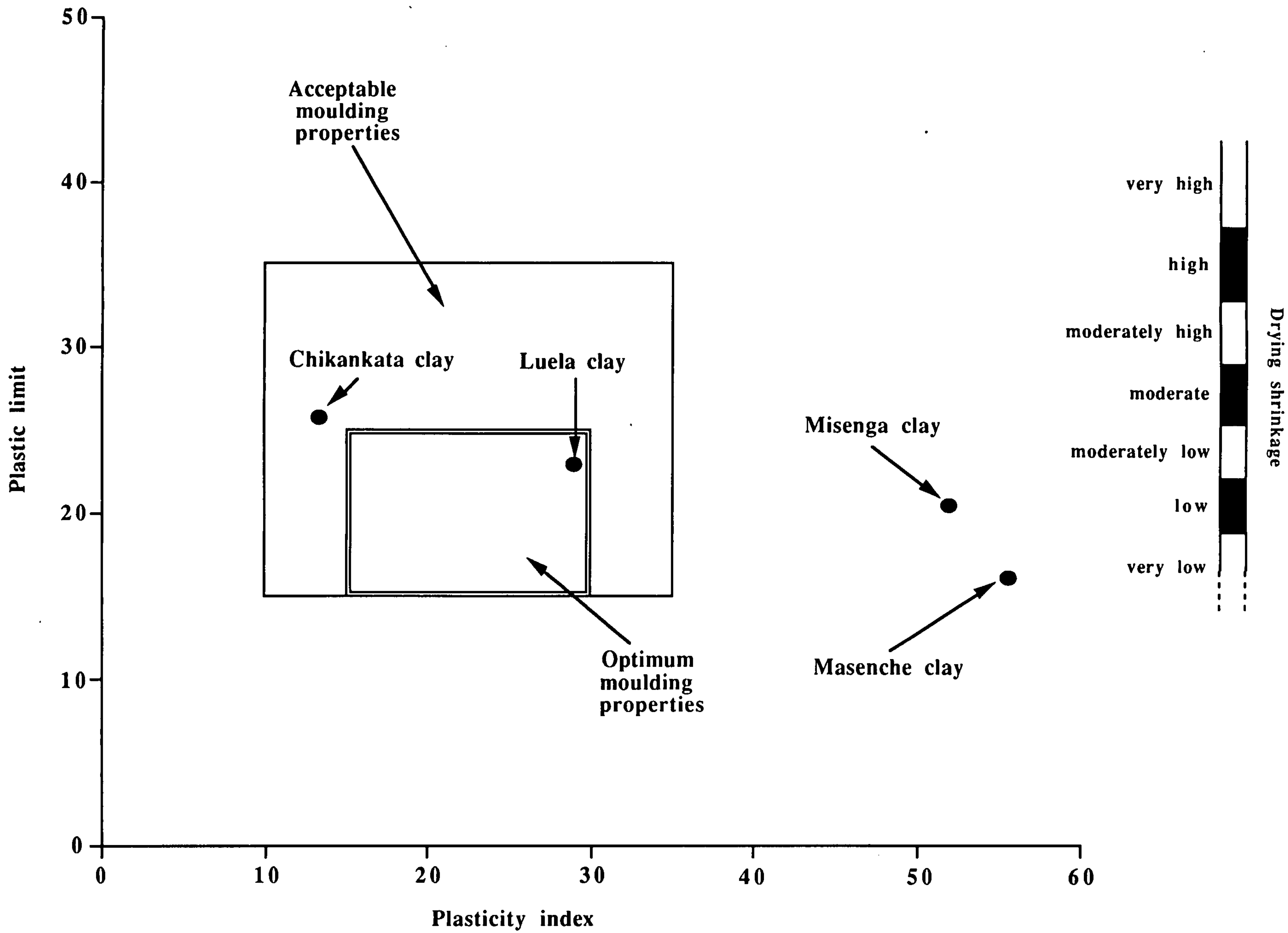


Figure 9. Plasticity of ceramic clays from Zambia (after Bain, 1978).

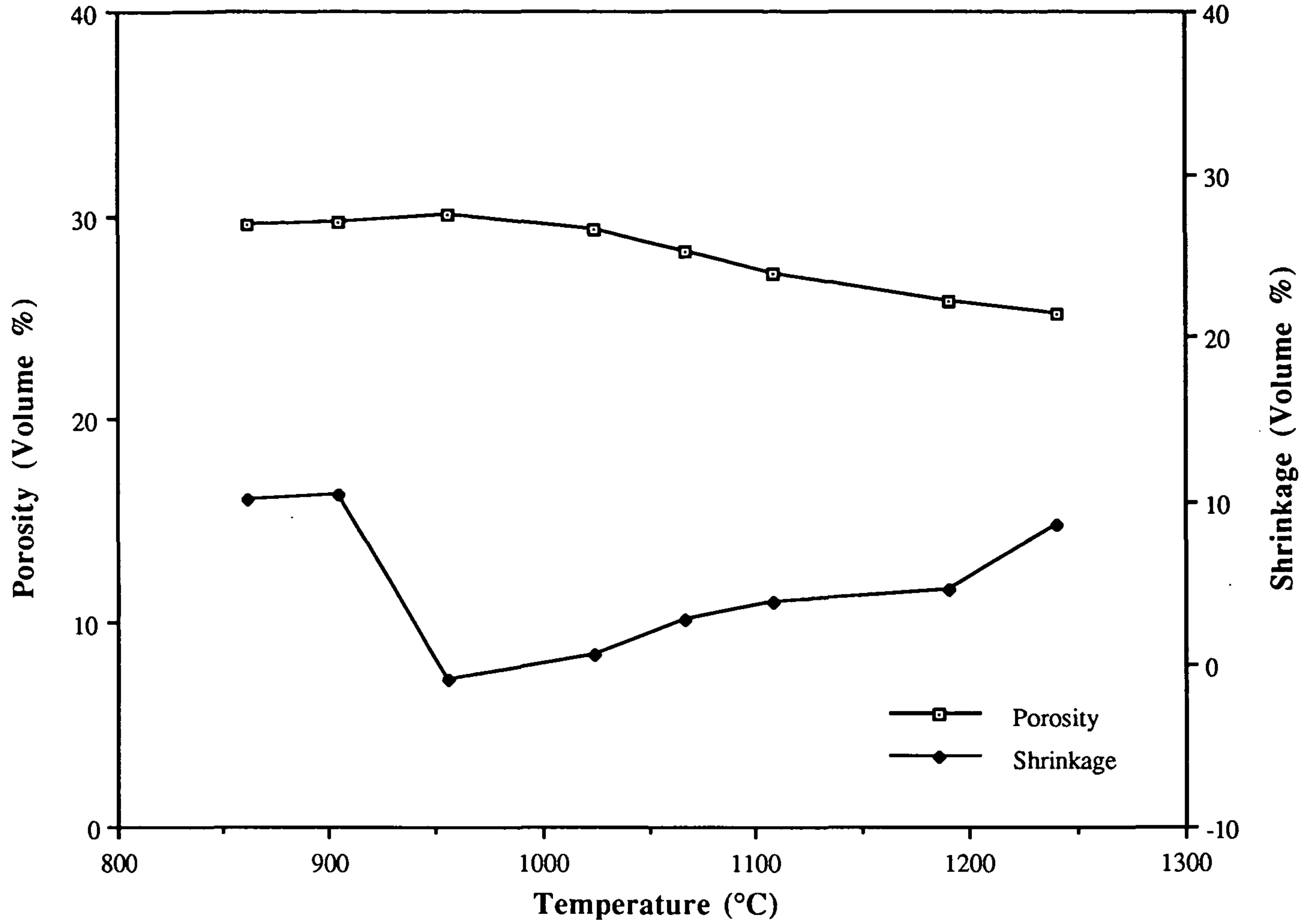


Figure 10. Vitrification curve for Masenche clay, Northern province, Zambia

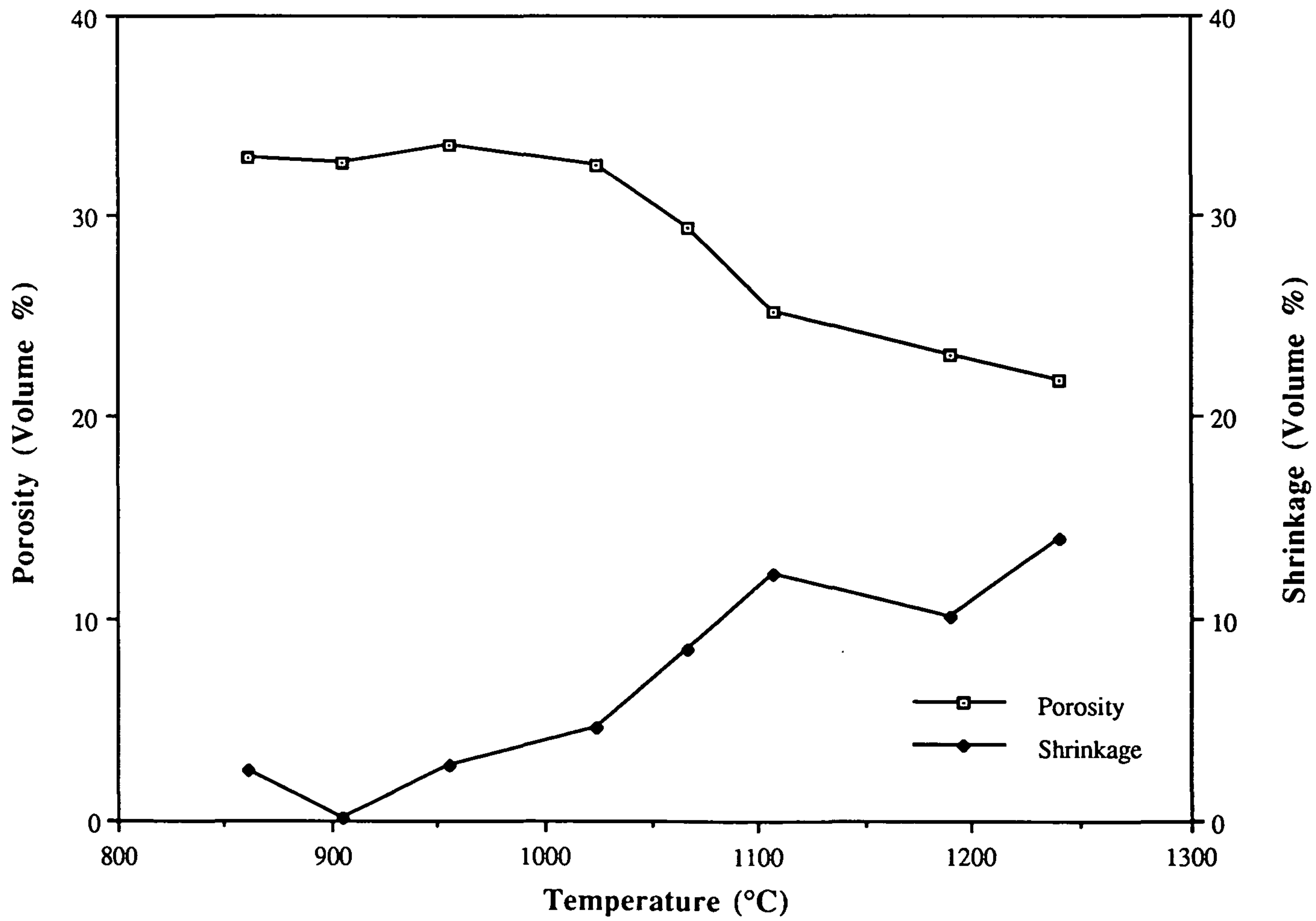


Figure 11. Vitrification curve for Luela clay, Zambia

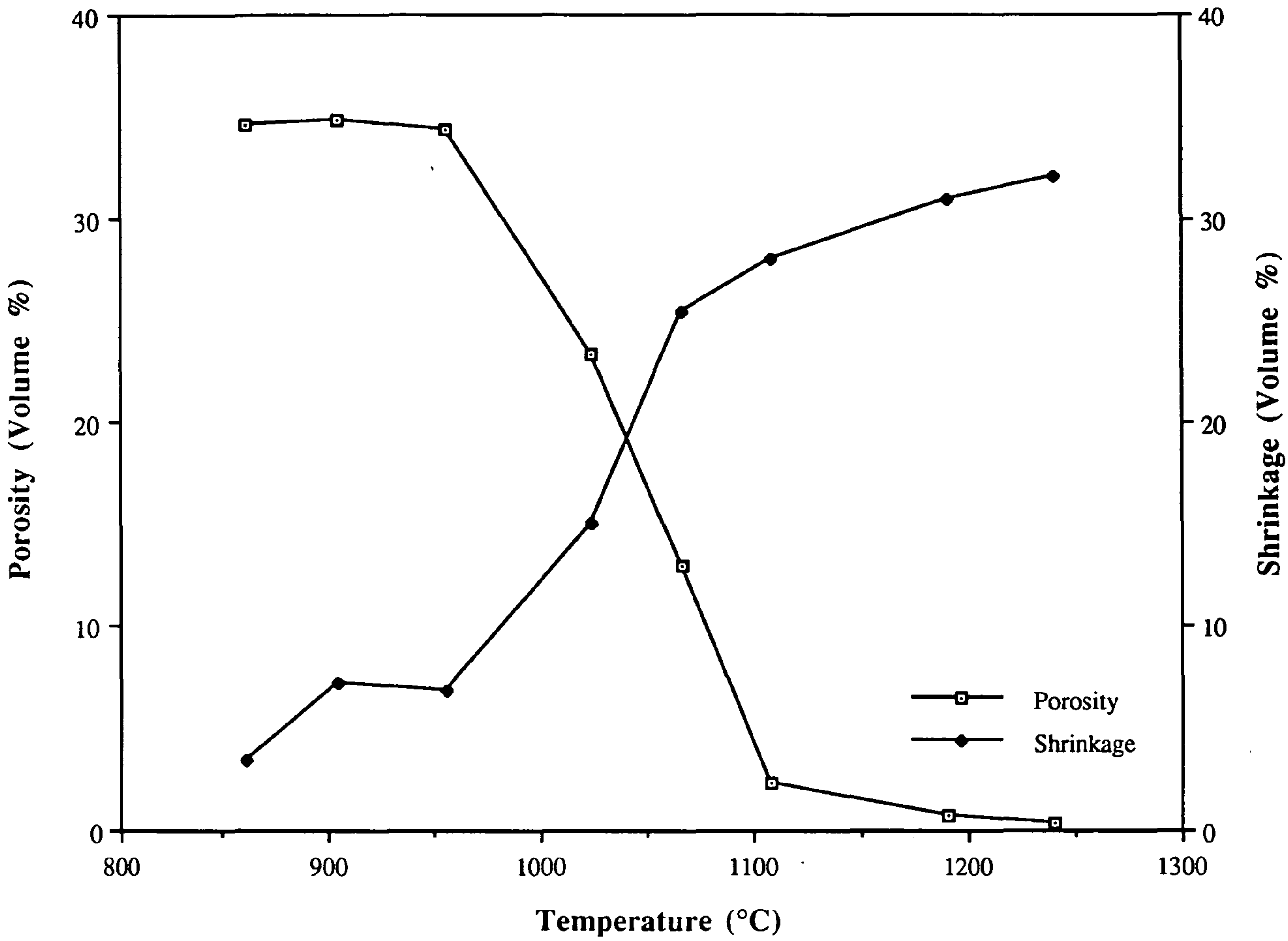


Figure 12. Vitrification curve for Misenga clay, Zambia.

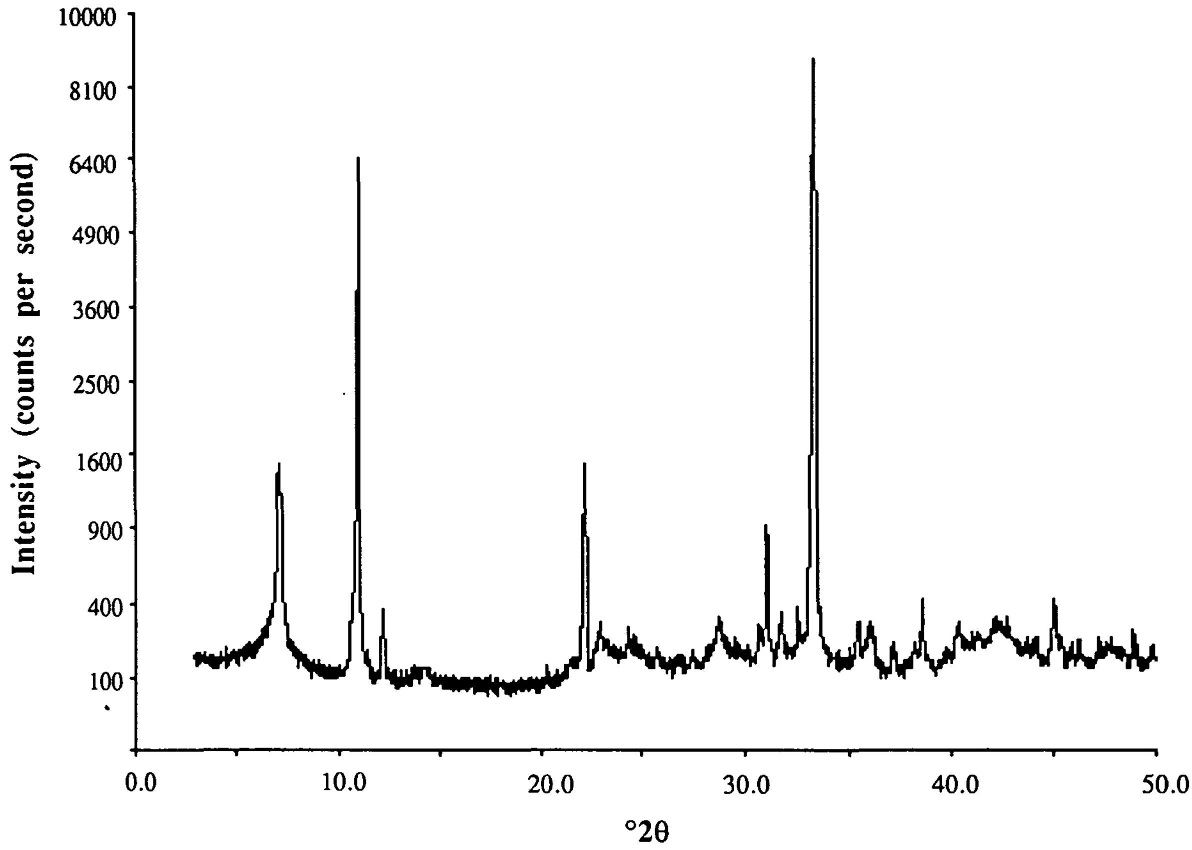


Figure 13. X-ray diffraction trace of Chikankata clay, Southern Province, Zambia.

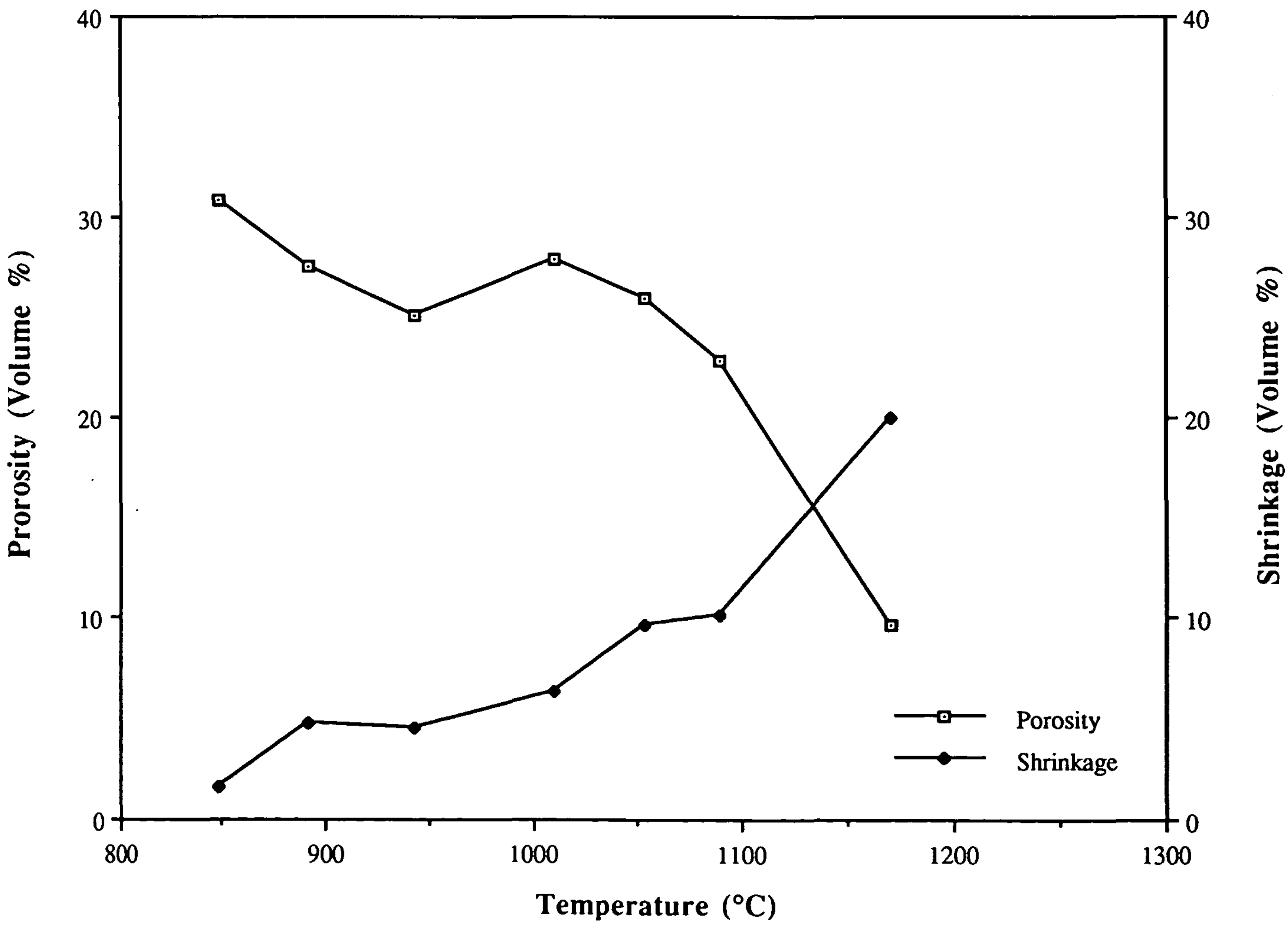


Figure 14. Vitrification curve for Chikankata clay, Southern province, Zambia.