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Distr.
RESTRICTED

IO/R.22
18 November 1986

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

ENGLISH

# UTILIZATION OF LINTHIPE CERAMIC CLAYS

XP/MLW/86/041/11-50

**MALAWI**

Terminal report

Prepared for the Government of Malawi
by the United Nations Industrial Development Organization

Based on the work of M. Ibrahim Chaudry, expert in the
testing of ceramic raw materials

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V.86-62113
3429T

## Explanatory notes

The monetary unit in Malawi is the kwacha (K).

References to tonnes (t) are to metric tonnes.

Besides the common abbreviations, symbols and terms, the following have been used in this report:

GSD Geological Survey Department of Malawi

LOI Loss on ignition

ABSTRACT

In response to a request by the Government of Malawi to the United Nations Industrial Development Organization (UNIDO) for the financing of a short-term consultancy in the testing of ceramic raw materials, the project "Utilization of Linthipe ceramic clays" (XP/MLW/86/041) was approved in February 1986 and an expert fielded in May 1986 for a total of three months.

The immediate objective of the project was to assist the Geological Survey Department (GSD) of Malawi in developing laboratory research procedures and a methodology for the testing of Linthipe ceramic clays.

The expert, working at the laboratory of GSD in collaboration with the local staff, carried out a series of physical and chemical tests on samples of clays and other minerals collected by GSD. Various ceramic bodies and glazes were compounded from local raw materials, and their testing indicates very satisfactory properties.

In view of those encouraging results, the expert recommends the establishment of a pilot production unit for ceramics, which should not only contribute to an improvement of the productivity and product quality of the existing ceramic industry by undertaking further research and development work on indigenous raw materials and arranging training in ceramic technology, but also serve as a common facility centre for local entrepreneurs.

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# INTRODUCTION

## A. Background

The art of making pottery has been practiced since the earliest civilizations. Indeed, the examination of pottery fragments has been one of the best tools of archaeologists. Burnt clayware has been found dating from about 15,000 B.C. and pottery was well developed as an industrial art in Egypt by about 5,000 B.C.

At one time, almost all ceramic products were made, wholly or partly, from clay which during its manufacture had been shaped and then fired to a temperature high enough to give the required strength. Today ceramics are defined as products manufactured by heat treatment of non-metallic inorganic oxides. In spite of the expansion in the field of ceramics, the volume of clay-based ceramics manufactured is much greater than that of non-clay ceramics, and clay is still regarded as the basic and most important of all ceramic materials.

The variety of clay-based industrial products is enormous; the first product coming to one's mind is tableware, i.e. cups, saucers, plates etc., but there are numerous other products of daily use such as bricks and tiles of all types, earthenware, porcelain, sanitary ware, sewer pipes, chemical porcelain, acid-resistant ware, heat-resistant bricks, electrical insulators and many others.

## B. Official arrangements and objectives

In response to a request by the Government of Malawi to the United Nations Industrial Development Organization (UNIDO) for the financing of a short-term consultancy in the testing of ceramic raw materials, the project "Utilization of Linthipe ceramic clays" (XP/MLW/86/041) was approved in February 1986 and an expert fielded in May 1986 for a total of three months.

The immediate objective of the project is to assist the Geological Survey Department (GSD) of Malawi in developing laboratory research procedures and a methodology for the testing of Linthipe ceramic clays. GSD has carried out a great deal of research on those clays and found them suitable for the production of a number of ceramic articles which, however, need to be glazed due to their porosity. Since the glaze currently in use is unsatisfactory, research on suitable glazes is being undertaken. As the local staff involved in that exercise have a limited knowledge in ceramics, the services of an expert were requested.

The series of physical and chemical tests on Linthipe clays was carried out in the Industrial Minerals Laboratory of GSD at Zamba, where the expert worked in collaboration with the local laboratory staff.

## RECOMMENDATIONS

1. It is strongly recommended that a pilot plant be established at Linthipe for the semi-commercial production of tableware, sanitary ware, wall and floor tiles, technical ceramics and high-alumina refractories. As a result of three months of research and development work on Malawian ceramic raw materials, it has been established that the above-mentioned items can be produced locally, which can be regarded as a step towards a self-reliant economy.

2. The pilot plant should not only serve for training in ceramic technology, but also for further research in and development of indigenous raw materials.

3. Furthermore, the pilot plant should also serve as a common facility centre for the local entrepreneurs, where their raw materials would be processed, and possibly their products fired in the kilns of the pilot plant.

4. For the firing of tableware new furnace designs (downdraft and updraft kilns) utilizing local coal from the Kaziwiziwi coal mine, should be tested. They should ultimately be introduced in village pottery industries to ensure a better output and bigger profit margin for the Malawian potters.

5. Additional research projects on technical ceramics and laboratory glass should be initiated at the pilot plant, which should help to establish meaningful linkages between the University of Malawi, the Geological Survey Department and the industry.

# I. AVAILABILITY AND COMPOSITION OF LOCAL CERAMIC RAW MATERIALS

## A. Clays

Two ceramic clay deposits are reported in Malawi. One is at Nkhande (Ntcheu) with an approximate reserve of 0.15 million tonnes and the second one is at Linthipe (Dedza) with an estimated reserve of 14 million tonnes (area indicated in figure I). The chemical analysis of Linthipe clay is given in table 1, together with that of Pugu clay (United Republic of Tanzania), Masuku clay (Zambia) and of china clays from New Zealand, the United Kingdom of Great Britain and Northern Ireland and the United States of America for comparison. Its particle size, up to 46-71 per cent, is less than 2 microns. The intention was to use this clay in the manufacture of tableware and refractories; however, so far little work has been done in the field of ceramics. The Linthipe clay was beneficiated by water-washing, a technique which eliminated most of the sandy particles such as magnetite, feldspar, amphibole, garnets etc. The results are given in table 2.

## B. Feldspar

This material contains fluxing oxides like Na and K, Ca and Li, which help to bring down the maturing temperatures of ceramic ware and also hasten the formation of the glass phase which acts as bond between other phases. A number of deposits of feldspars are reported in Malawi, e.g. Ntcheu (Dedza), Nsanje and Mlindi (Mwanza). The chemical analysis of the Ntcheu and Nsanje feldspars are given in table 3, together with the feldspar from Siavonga in Zambia for comparison.

## C. Sand

Sand acts as a filler in ceramic bodies, facilitates and accelerates the drying of green ceramic ware and gives strength to the fired body. In glasses and ceramic bodies it is used to control the thermal expansion.

A deposit of sand is reported in Mchinji Dambos, with estimated reserves of 0.72 million tonnes. Its chemical analysis is given in table 3, together with sand from Kapiri-Mposhi in Zambia for comparison.

## D. Nepheline syenite

Nepheline syenite has a higher alkali content than feldspar and is thus a more vigorous flux for ceramic bodies. It can be used in place of feldspar in body compositions, allowing lower firing temperatures and greater firing ranges than those obtainable with feldspar, resulting in less warpage of the ware during firing.

There are two sources of that mineral: one at Chikangawa (5 million tonnes) and the other is at Mangolowe (0.5 million tonnes). A chemical analysis of the Chikangawa nepheline syenite is given in table 4 together with others for comparison.

Figure I. Location of Linthipe clay deposits

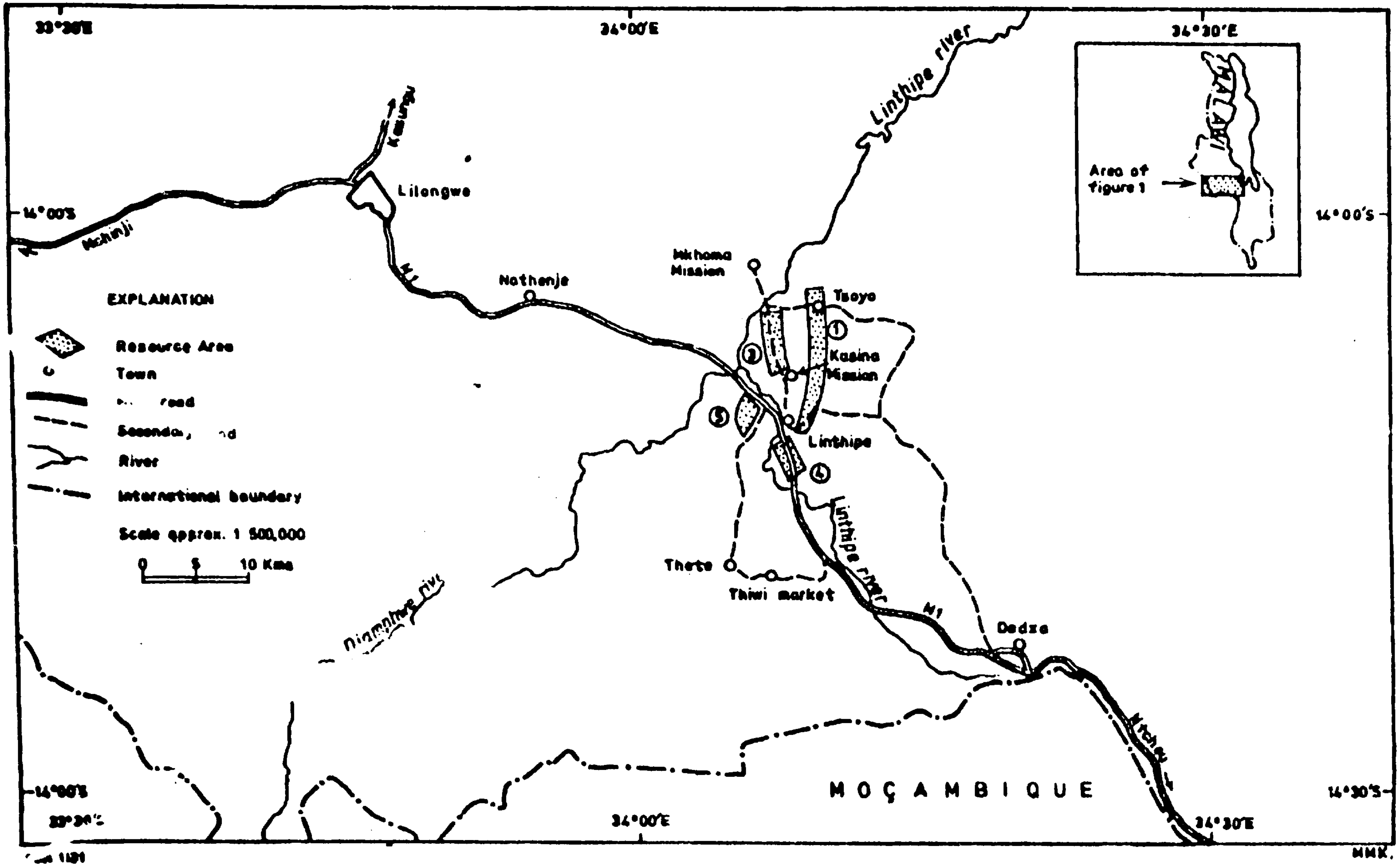


Table 1. Chemical composition of various china clays
(Percentages)

| Origin | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | CaO | MgO | $K_2O$ | $Na_2O$ | LOI |
|---|---|---|---|---|---|---|---|---|---|
| **United Kingdom of Great Britain and Northern Ireland** | | | | | | | | | |
| 1. | 48.50 | 36.60 | 0.56 | 0.05 | 0.10 | 0.10 | 1.92 | 0.09 | 11.97 |
| 2. | 47.20 | 37.60 | 0.50 | 0.05 | 0.20 | 0.20 | 1.35 | 0.07 | 12.62 |
| 3. | 45.7 | 39.16 | 0.78 | 0.14 | 0.21 | 0.17 | 1.26 | 0.06 | 12.72 |
| 4. | 47.48 | 37.75 | 0.58 | 0.03 | 0.19 | 0.20 | 1.31 | 0.20 | 12.46 |
| 5. | 48.20 | 37.20 | 0.65 | 0.05 | 0.08 | tr. | 0.75 | 0.70 | 13.08 |
| **United States of America** | | | | | | | | | |
| 1. | 44.70 | 39.50 | 0.34 | 1.02 | 0.11 | 0.07 | 0.02 | 0.03 | 13.96 |
| 2. | 45.24 | 38.57 | 0.30 | 1.45 | 0.10 | 0.17 | 0.26 | 0.11 | 13.86 |
| 3. | 45.05 | 39.50 | 0.20 | 1.43 | tr. | 0.20 | 0.12 | 0.03 | 13.53 |
| 4. | 44.00 | 38.60 | 0.51 | 1.70 | 0.15 | 0.09 | 0.09 | 0.12 | 14.67 |
| 5. | 44.94 | 38.83 | 0.31 | 1.41 | 0.09 | tr. | 0.18 | 0.04 | 14.12 |
| 6. | 45.11 | 38.99 | 0.46 | 1.46 | 0.12 | 0.04 | 0.06 | 0.03 | 13.97 |
| **New Zealand** | | | | | | | | | |
| 1. | 50.00 | 35.40 | 0.14 | 0.34 | 0.07 | 0.04 | 0.02 | 0.07 | 13.80 |
| **Zambia (Musuku)** | | | | | | | | | |
| 1. | 47.82 | 37.38 | 0.02 | 0.30 | 0.86 | 0.09 | 1.43 | - | 13.0 |
| 2. | 48.29 | 37.29 | 0.03 | 0.02 | 0.71 | - | 1.07 | 0.07 | 12.49 |
| 3. | 47.40 | 37.60 | 0.12 | 0.10 | 0.30 | 0.06 | 1.10 | 0.27 | 13.02 |
| **United Republic of Tanzania (Fugu)** | | | | | | | | | |
| | 52.40 | 33.10 | 1.54 | 0.53 | 0.03 | 0.02 | 0.02 | 0.10 | 12.34 |
| **Malawi (Linthipe)** | | | | | | | | | |
| 1. | 46.73 | 32.45 | 2.20 | 0.59 | 1.09 | 0.31 | 0.23 | 0.40 | 11.40 |
| 2. | 47.6 | 34.7 | 1.9 | 0.42 | 0.32 | 0.22 | 0.14 | 0.39 | 14.03 |
| 3. | 48.7 | 34.2 | 1.5 | 0.8 | 0.2 | 0.2 | 1.0 | 0.2 | 13.6 |

Table 2. Clay washing results

| Sample | Weight of raw samples (kg) | Weight of residues (kg) | Percentage of residues | Percentage of clay |
|---|---|---|---|---|
| 1 | 3.7 | 0.6199 | 16.8 | 83.2 |
| 2 | 3.7 | 0 6272 | 17.0 | 83.0 |
| 3 | 3.7 | 0.5751 | 15.5 | 84.5 |
| 4 | 4.6 | 0.7922 | 17.5 | 82.5 |
| 5 | 5.2 | 0.3673 | 7.1 | 92.9 |
| 6 | 5.4 | 0.4176 | 7.7 | 92.3 |
| 7 | 5.5 | 0.4357 | 7.9 | 92.1 |
| 8 | 5.7 | 0.5034 | 8.8 | 91.2 |
| 9 | 5.1 | 0.4006 | 7.9 | 92.1 |
| 10 | 3.9 | 0.3792 | 9.7 | 90.3 |
| 11 | 2.3 | 0.3538 | 15.4 | 84.6 |
| Average | 4.4 | 0.4975 | 11.9 | 88.1 |

Table 3. Chemical composition of Zambian and Malawian feldspars and sands

| | Feldspar | | | Sand | |
|---|---|---|---|---|---|
| Compound | Zambian Siavonga | Malawian Ntcheu | Malawian Nsanje | Zambian Kapiri-Mposhi | Malawian Mchinji |
| $SiO_2$ | 69.1 | 71.1 | 76.41 | 98.59 | 96.73 |
| $Al_2O_3$ | 16.8 | 15.5 | 12.76 | 1.85 | 1.38 |
| MgO | 0.06 | 0.08 | 0.01 | 0.21 | 0.01 |
| CaO | 0.28 | 0.26 | 0.10 | 0.12 | 0.04 |
| $Fe_2O_3$ | 0.07 | 0.15 | 0.06 | 0.32 | 0.11 |
| $TiO_2$ | 0.09 | 0.05 | 0.00 | 0.43 | - |
| $K_2O$ | 10.16 | 9.92 | 8.53 | 0.28 | - |
| $Na_2O$ | 3.01 | 2.97 | 1.87 | 0.06 | - |
| LOI | 1.49 | 0.41 | 0.37 | 0.05 | 0.21 |

Table 4. Chemical composition of selected nepheline syenites
(Percentages)

| Compound | Average Canadian nepheline syenite | Nepheline syenite gneiss-SB 192, Norway | Average nepheline syenite, Chikangawa, Malawi |
|---|---|---|---|
| $SiO_2$ | 59.18 | 59.37 | 59.91 |
| $TiO_2$ | 0.06 | 0.19 | 0.23 |
| $Al_2O_3$ | 23.06 | 22.99 | 20.98 |
| $Fe_2O_3$ | - | 0.53 | 0.63 |
| FeO | 2.15 | 4.02 | 0.74 |
| MnO | - | 0.14 | 0.05 |
| MgO | 0.17 | 0.04 | 0.08 |
| CaO | 0.76 | 0.68 | 0.28 |
| $Na_2O$ | 10.48 | 9.27 | 9.46 |
| $K_2O$ | 3.94 | 2.20 | 4.62 |
| LOI | 0.40 | 0.86 | 0.65 |
| $P_2O_5$ | 0.62 | 0.01 | 0.04 |
| $CO_2$ | - | - | - |
| $ZrO_2$ | 0.05 | - | - |
| Total | 100.27 | 100.02 | 97.67 |

# II. TESTING OF LOCAL CERAMIC RAW MATERIALS

## A. Preparation of raw materials

### Linthipe clay

The Linthipe clay was washed by a simple water washing technique using plastic buckets. All the clay water suspension was passed through a 100 mesh, and the washed clay was dried in an oven at 110 °C. The clay contents and the percentage of residues are reported in table 2. The dried clay was further ground to pass through a 200 mesh. The chemical composition of washed and unwashed clays is given in table 5. All body compositions were prepared from washed, 200-mesh Linthipe clay.

Clay washing tanks were designed, constructed and installed near the laboratory for an efficient recovery of the clay. The layout of that clay washing plant is shown in figure II.

Table 5. Chemical composition of unwashed and washed Linthipe clay (Percentages)

| Compound | Unwashed | Washed |
|---|---|---|
| $Al_2O_3$ | 31.00 | 31.76 |
| $Fe_2O_3$ | 2.12 | 2.23 |
| CaO | 0.70 | 0.56 |
| MgO | 0.25 | 0.33 |
| $Na_2O$ | 0.50 | 0.59 |
| $K_2O$ | 0.28 | 0.42 |
| $SiO_2$ | 44.32 | 45.00 |
| LOI | 20.58 | 17.61 |
| $TiO_2$ | 0.41 | 0.21 |
| pH | 7.15 | 7.15 |
| $SO_4$ | 0.00% | 0.00% |

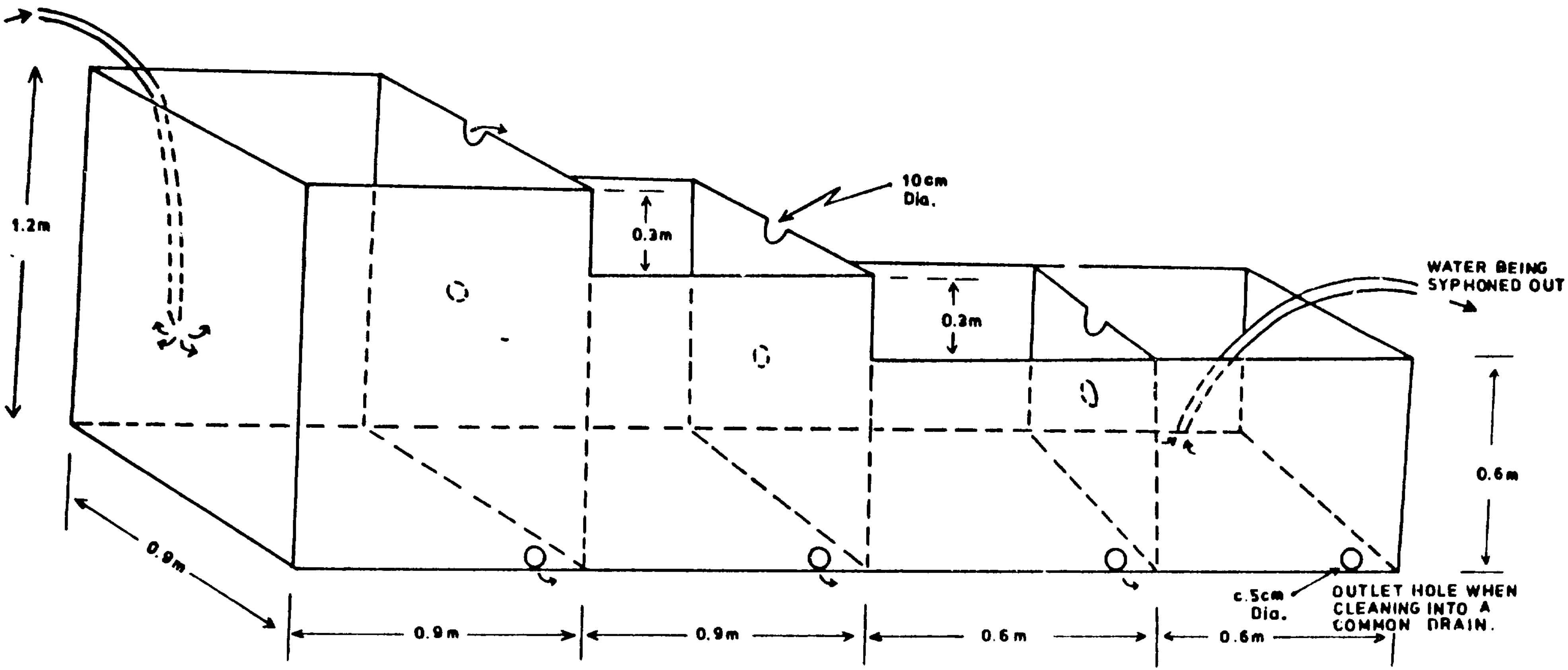
### Ntcheu feldspar

Ntcheu feldspar was crushed in a small jaw crusher and then ground in a ceramic mortar with pestle, to a size passing through a 200 mesh. Ntcheu feldspar was found most suitable according to the evaluations made, and therefore, for the purpose of this study, only that feldspar was used in the formulation of ceramic bodies and glazes.

### Sand

Sand was washed with water, dried at 110 °C and then ground in a ceramic mortar (in the absence of a ball mill) to pass through a 200 mesh. Mchinji silica sand was used in compounding the ceramic bodies and glazes in the course of these investigations.

Figure II. Clay washing plant



Nepheline syenites

Since the Nepheline syenites of Chikangawa and Mongolowe were both found to be unsuitable, no such minerals were used in the formulation of ceramic bodies and glazes.

## B. Fired colour of various ceramic raw materials

Samples of clay, sand, feldspar, nepheline syenite, talc and limestone were fired at 1,000 and at 1,250 °C to examine their fired colour. It was observed that none of the soapstones, without beneficiation, can be used in ceramics because of their dirty colour due to impurities. The results are summarized in table 6.

Mchinji silica sand did not melt at 1,250 °C, but produced a good white colour; it was therefore found suitable for the glass and ceramic industry.

Chikangawa nepheline syenite melted at 1,250 °C, producing variegated greens in a white-to-transparent glass. It is therefore unsuitable for ceramics and glass, unless beneficiated.

All the Ntcheu soapstones produced orange-brown to dark-green powders at 1,250 °C, and cannot be used for ceramics, unless beneficiated.

Linthipe clay, at 1,250 °C, became of light cream colour with a tinge of very light yellow, which is perhaps due to the presence of titania. This clay can be used for the production of tableware, tiles, sanitary ware, insulators and in technical ceramics.

Table 6. Fired colour of various ceramic raw materials

| Material | Colour at 1,000 °C | Colour at 1,250 °C |
|---|---|---|
| Linthipe clay | Brownish white | Brownish-white powder |
| Mchinji silica sand | White powder | White powder |
| Ntcheu feldspar | White | White glass |
| Mlindi feldspar | | Dark-grey glass |
| Nsanje feldspar | | Light-cream glass |
| Chikangawa nephiline syenite | Greyish-brown powder | Variegated greens in a white to transparent glass |
| Ntcheu soapstone | Orange brown | Brownish grey |
| Machinga limestone (Chenkumbi - lowest quality type) | | Dark greenish-grey |

Ntcheu feldspar melted at 1,250 °C, forming white glass and could be safely used in the ceramic as well as in the glass industry, whereas Mlindi and Nsanje feldspars after melting produced dirty-coloured glasses. Therefore only the Ntcheu feldspar was found suitable for ceramics.

## C. Body compositions and casting properties

Various body compositions were prepared by mixing and grinding clays with different proportions of feldspar and sand. This was done in a small pot mill with a capacity of 2.5 kg, which was kept running for two to six hours with the required amount of water.

The major methods employed in the production of ceramic ware are:

(a) Slip casting;

(b) Plastic making;

(c) Semi-dry pressing;

(d) Dry pressing.

Due to the lack of equipment in the laboratories of the Geological Survey Department, only the slip casting method could be used. Slips of various densities were prepared and their casting properties were observed. The viscosity and thixotropy were not quantified due to the inavailability of a torsion viscometer. The slips were deflocculated with $Na_2CO_3$ and $Na_2SiO_3$ solutions in various quantities and proportions. The results are given in table 7.

Table 7. Composition and casting properties of ceramic bodies

| | Body composition number | | | | | |
|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI |
| Clay | 20 | 35 | 35 | 40 | 45 | 50 |
| Silica sand | 40 | 35 | 30 | 30 | 30 | 25 |
| Feldspar | 35 | 30 | 35 | 30 | 25 | 25 |
| Distilled water ($cm^3$) | 40 | 45 | 45 | | | |
| $Na_2CO_3$ ($cm^3$) | 1 | 1.7 | 1.5 | 1.3 | | |
| $Na_2SiO_3$ ($cm^3$) | 1 | 2 | 1.5 | 1.8 | | |
| Grinding time (hours) | 4 | 4 | 4 | 4 | | |
| Casting properties | Good slip, good products. Few cracked. | Mostly good products. One cracked. | Good slip. Long time to release product from mould. | Good slip, good products. | | |

## D. Drying and firing shrinkage

### Drying

In the drying of ceramics, water vapour is released into the surrounding atmosphere. The main requirements for successful drying are heat and air, with adequate control of both for good results. Since no humidity controls existed, the ceramic ware was dried in the sun and subsequently in an electric oven at 110 °C. This was done very slowly, in order to minimize cracking and warping.

### Biscuit firing and glost firing

The dried ceramic ware was biscuit-fired at 1,000 °C for two hours in an electric furnace (pottery-craft type P5900). Extreme care was taken regarding the rate of firing especially at the alpha to beta quartz conversion at 537 °C, since this change produces expansion in the ceramic body (see figure III). Since organic matter present in the body has to burn off at any temperature, the rate of temperature rise should be between 300 and 700 °C. The kiln atmosphere was kept strongly oxidizing, so that the carbonaceous matter could burn to $CO_2$. As all tested body compositions contained quartz, temperature changes would have caused cracking in such bodies.

Precautions were again taken regarding the rate of firing above 900 °C, when ceramic bodies contract due to the formation of the liquid phase which leads to porosity reduction and shrinkage.

The glost firing of the ceramic ware was done at various temperatures, i.e. 1,220, 1,225, 12,230, 1,240 and 1,250 °C for two hours after the application of glaze on the fettled ceramic ware.

### Property measurements

Drying shrinkage, firing shrinkage, water absorption, bulk density and apparent porosity were determined on biscuit-fired pieces according to the ASTM C373-56. All staff of the laboratory were trained in these techniques. The test results are given in table 8.

## E. Glaze preparation

Various types of raw glazes were prepared by mixing the materials and grinding them in a pot mill for four hours. The density of the glazes was kept between 1.4 and 1.5 g/cm$^3$. Before their application, the glazes were sieved through a 120 mesh. The biscuit-fired bodies were glazed by the dipping method and subsequently fired for two hours at temperatures ranging from 1,200 to 1,250 °C, whereby the atmosphere of the kiln was kept in an oxidizing state. The compositions of the glazes and the test results are given in table 9.

## F. Plaster of Paris

Plaster of Paris was made from local gypsum. After hand-picking the impurities such as quartz particles, calcrete and laterite nodules, the gypsum was thoroughly washed, sun-dried, and then calcined in an oven at 130 °C for two hours. Unwanted impurities were further hand-picked, and that hand-sorted, calcined gypsum was recalcined at 160 °C for two hours and finely ground to pass through a 200 mesh (see table 10). This plaster of Paris was used for the production of pottery moulds and partitions. A sample partition board made from the local plaster of Paris was displayed at the July 1986 Malawi National Fair. The consistence standard and the initial setting time of the plaster of Paris were determined by means of a Vicat apparatus. The results are given in table 11.

Figure III. Typical firing rate curves of ceramic articles

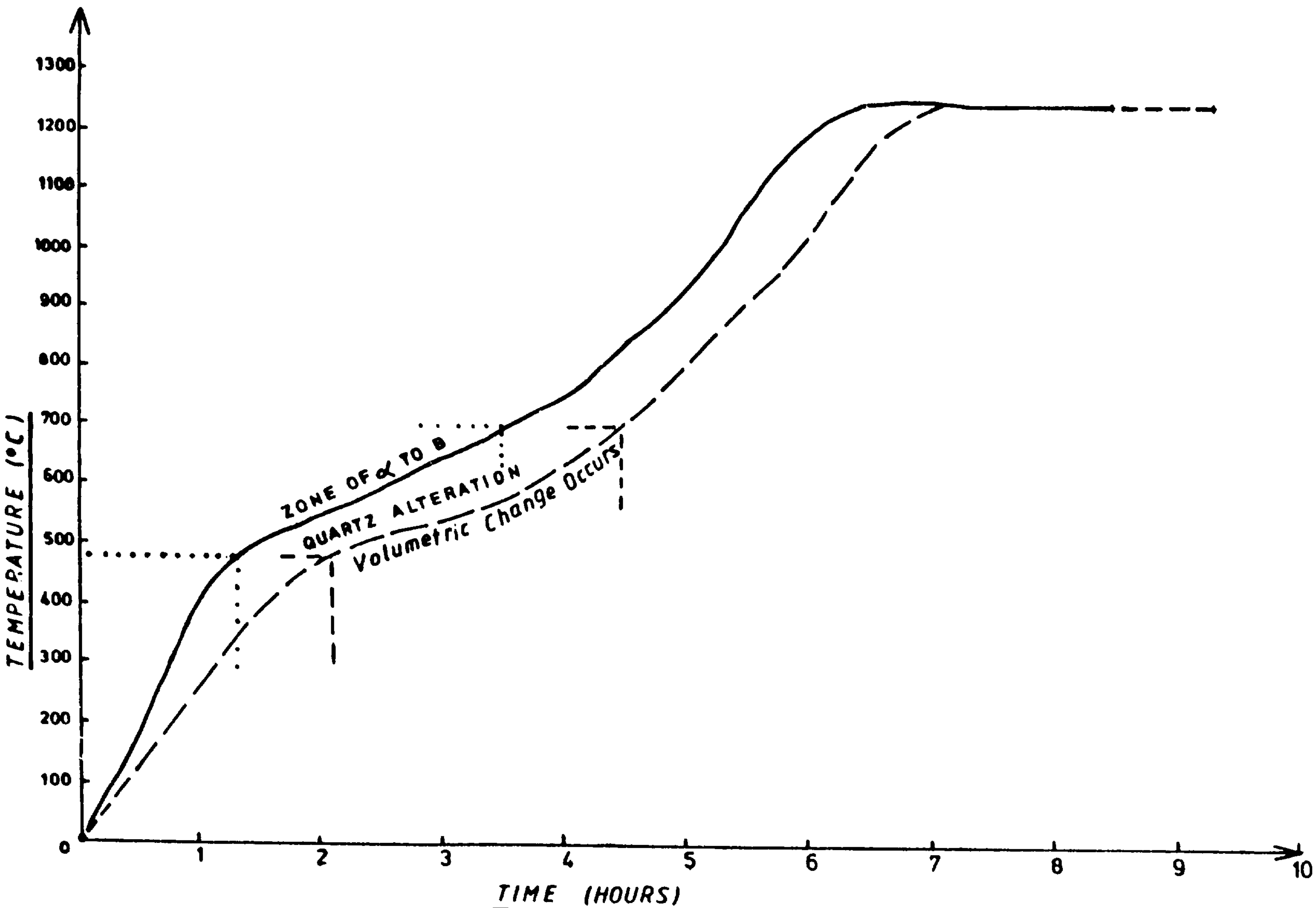


Table 8. Firing properties of various ceramic bodies

| Body and sample No. | Temperature (°C) | Density ($g/cm^3$) | Water absorption (%) | Linear shrinkage (%) |
|---|---|---|---|---|
| <u>Body composition I</u>: | | | | |
| 1 | 1,000 | 1.7 | 17.1 | 6.9 |
| 2 | 1,000 | 1.7 | 17.0 | 6.5 |
| 3 | 1,000 | 1.8 | 16.7 | 6.6 |
| Average | 1,000 | 1.7 | 16.9 | 6.7 |
| <u>Body composition II</u>: | | | | |
| 1 | 1,200 | 2.2 | 2.5 | 15.8 |
| 2 | 1,200 | 2.3 | 1.9 | 15.9 |
| 3 | 1,200 | 2.3 | 2.1 | 15.4 |
| Average | 1,200 | 2.3 | 2.2 | 15.7 |

Table 9. Composition and firing properties of various glazes

| Composition | | Applied to body No. | Firing temperature for two hours (°C) | Results |
|---|---|---|---|---|
| Material | Percentage | | | |
| <u>Glaze No. 1</u>: | | | | |
| Clay<br>Feldspar<br>Silica sand<br>Whiting<br>Zinc oxide | 10<br>60<br>15<br>20<br>5 | I | 1,220 | Glaze matured alright. There was very little translucency. A trace of pin-holes observed. Material was underfired at 1,220 °C. Temperature to be raised to 1,225 °C for two hours. Resultant colour was greyish-white. |
| | | II | 1,220 | Glaze matured alright. Very little translucency. Colour as above. |
| | | III | 1,225 | Glaze matured well. No pin-holes observed, no crazing and no blistering. Colour as above. |

continued

Table 9 (continued)

| Composition: Material | Composition: Percentage | Applied to body No. | Firing temperature for two hours (°C) | Results |
|---|---|---|---|---|
| | | IV | 1,225 | Glaze matured well. No pin-holes, crazing and blistering observed. Colour as above. |
| **Glaze No. 2:** | | | | |
| Clay | 9 | I | 1,225 | Glaze matured alright. No pin-holes, no crazing and blistering. Cream colour. |
| Feldspar | 40 | | | |
| Silica sand | 26 | | | |
| Whiting | 20 | | | |
| Zinc oxide | 5 | | | |
| | | II | 1,225 | As above. |
| | | III | 1,225 | As above. |
| | | IV | 1,225 | As above. |
| **Glaze No. 3:** | | | | |
| Clay | 9 | I | 1,225 | Matured well. No pin-holes, no crazing. Light-brown colour achieved. |
| Feldspar | 41 | | | |
| Silica sand | 26 | | | |
| Whiting | 20 | | | |
| Zinc oxide | 4 | | | |
| Calcium carbonate | 1 | | | |
| | | II | 1,225 | Good results as above; colour as above. |
| | | III | 1,225 | Results as above. |
| | | IV | 1,225 | Results as above. |
| **Glaze No. 4, opaque:** | | | | |
| Clay | 9 | II | 1,225 | Matured well. Light green colour. |
| Feldspar | 41 | | | |
| Silica sand | 26 | | | |
| Whiting | 20 | | | |
| Zinc oxide | 4 | | | |
| Copper oxide | 1 | | | |
| | | IV | 1,225 | Matured very well, excellent results. Colour as above. |

continued

Table 9 (continued)

| Composition: Material | Composition: Percentage | Applied to body No. | Firing temperature for two hours (°C) | Results |
|---|---|---|---|---|
| **Glaze No. 5:** | | | | |
| Clay | 4.5 | II | 1,225 | Matured alright. No pin-holing or blistering. Opaque-white colour. |
| Feldspar | 20.5 | | | |
| Silica sand | 12.5 | | | |
| Whiting | 10.0 | | | |
| Tin oxide | 2.5 | | | |
| **Glaze No. 6:** | | | | |
| Clay | 10 | I | 1,225 | Matured well; without pin-holes, blistering etc. Blue colour achieved. |
| Feldspar | 40 | | | |
| Silica sand | 24 | | | |
| Whiting | 20 | | | |
| Zinc oxide | 4 | | | |
| Cobalt oxide | 2 | | | |
| | | II | 1,225 | As above. |
| | | III | 1,225 | As above. |
| | | IV | 1,225 | As above. |
| **Glaze No. 7:** | | | | |
| Clay | 10 | I | 1,225 | Excellent results achieved. No pin-holing, no crazing, no blistering. Beautiful brown colour. |
| Feldspar | 40 | | | |
| Silica sand | 24 | | | |
| Whiting | 20 | | | |
| Zinc oxide | 4 | | | |
| Nickel oxide | 2 | | | |
| | | II | 1,225 | As above. |
| | | III | 1,225 | As above. |
| | | IV | 1,225 | As above. |
| **Glaze No. 8:** | | | | |
| Clay | 8 | II | 1,220, then 1,230 (2 hours each) | Glaze did not mature well at 1,220 °C. Crazing and pin-holing observed. Pale white colour achieved. At 1,230 °C samples were overfired. |
| Feldspar | 40 | | | |
| Silica sand | 23 | | | |
| Whiting | 19 | | | |
| Zirconium oxide | 8 | | | |
| Zinc oxide | 2 | | | |

continued

Table 9 (continued)

| Composition: Material | Composition: Percentage | Applied to body No. | Firing temperature for two hours (°C) | Results |
|---|---|---|---|---|
| | | IV | 1,220, then 1,230 (2 hours each) | As above. |
| | | IV | 1,225 | Glaze matured well, excellent results. Pale white colour obtained. |
| Glaze No. 9: | | | | |
| Clay | 8 | IV | 1,220, then 1,230 (2 hours each) | At 1,220 °C samples were under-fired and showed pin-holes; crazing in some. At 1,230 °C, samples developed cracks, while crazing and pin-holes were still present. Thus at 1,220 °C, samples were under-fired and at 1,230 °C over-fired. White colour resulted. |
| Feldspar | 40 | | | |
| Silica sand | 22 | | | |
| Whiting | 16 | | | |
| Zirconium oxide | 12 | | | |
| Zinc oxide | 2 | | | |
| | | IV | 1,225 | Glaze matured well; excellent results achieved, no crazing nor pin-holes observed. White colour resulted. |
| Glaze No. 10: | | | | |
| Clay | 9 | I | 1,220, then 1,230 (2 hours each) | Glaze did not mature well. At 1,220 °C samples were under-fired, at 1,230 °C they were overfired. Glaze was too thick. Crazing, pin-holing and blistering observed. Dark-blue colour achieved. |
| Feldspar | 40 | | | |
| Silica sand | 23 | | | |
| Zinc oxide | 2 | | | |
| Whiting | 20 | | | |
| Cobalt oxide | 2 | | | |
| Iron oxide | 2 | | | |
| Manganese dioxide | 2 | | | |
| | | IV | 1,225 | Glaze matured well. Excellent results obtained. No crazing nor pin-holing. Dark blue (navy) colour achieved. |

Table 10. Results of sieve analysis of gypsum

| Material | Percentage of particles of different size | | |
|---|---|---|---|
| | 10 to 4 mm | 4 to 3 mm | 3 to 1.6 mm |
| Clean gypsum | 84.0 | 92.7 | 76.1 |
| Quartz | 2.5 | 1.4 | 18.0 |
| Calcrete | 11.4 | 2.9 | 1.0 |
| Laterite | 2.1 | 3.0 | 4.9 |
| Final production ratio | 1 | 3 | 5 |

Table 11. Determination of consistence standard and initial setting time for plaster of Paris

| Composition of mixture (%) | | Mixing time (min) | Plunger penetration from bottom (mm) | Results |
|---|---|---|---|---|
| Plaster of Paris | Water | | | |
| 100 | 45 | 2.5 | 40 | Setting within 3 minutes. Too little water |
| 100 | 60 | 2.5 | 25 | Setting quickly. Too little water. |
| 100 | 100 | 2 | 5 to 7 | Setting after 8.5 minutes. Right amount of water. |

Table 12. Glazing results on slip-cast cups

| Quantity of cups tested | Body composition No. | Glaze No. | Firing temperature (°C) | Firing time (h) | Results |
|---|---|---|---|---|---|
| 1 | IV | 1 | 1,225 | 2 | Excellent results; translucent cream colour. No pin-holes or blisters. |
| 5 | IV | 4 | 1,225 | 2 | Very good to excellent results; greeen colour. One cup with pin-holes and uneven glaze, probably due to insufficient glaze application. |
| 6 | IV | 7 | 1,225 | 2 | Excellent results; brown colour. All good, except two, without pin-holes, blisters and uneven spread of glaze. |
| 1 | IV | 9 | 1,225-1,300 | 2 | Good results: white opaque colour, varying from white to just off-white. |
| 1 | IV | 10 | 1,225-1,300 | 2 | Navy-blue colour. Very good results, except for blisters and few pin-holes due to over-firing. |

## III. CONCLUSIONS

A number of clay compositions were formulated from Linthipe clay, Mchinji silica sand, Ntcheu feldspar and Machinga limestone. After studying their physical and chemical characteristics, it has been concluded that clay body composition No. IV is the best of the lot. Its density is 2.3 after firing at 1,200 °C, while the water absorption is 2.2 per cent and the linear shrinkage 15.7 per cent. These properties fall in the category of porcelain/stoneware bodies. At 1,225 °C the body does not warp, and the translucency is quite good. The only flaw is that the colour of the body is off-white.

It was also found that a mixture of 40 per cent Linthipe clay, 30 per cent Mchinji silica sand and 30 per cent feldspar, with the addition of 1.3 $cm^3$ $Na_2CO_3$ and 1.8 $cm^3$ $Na_2SiO_3$ (all ground for four hours) produced a very good slip for the slip casting technique.

Various raw glazes were prepared from Linthipe clay, Ntcheu feldspar, Mchinji silica sand and Machinga limestone, with the addition of only 5 per cent ZnO. The glaze and body properties are quite fitting. The tests showed that the glazes matured best, without any pin-holes, blisters or crazing, when fired for two hours at 1,225 °C, in an oxidizing atmosphere.

Furthermore, the following range of different colours was achieved:

(a) Light green by adding 1 per cent of copper oxide;

(b) White opaque by adding 2.5 per cent of tin oxide;

(c) Navy blue by adding 2 per cent of cobalt oxide;

(d) Brown by adding 2 per cent of nickle oxide.

In another series of tests, a number of cups were slip-cast from body composition No. IV and different glazes applied to them. The results, which were very satisfactory throughout, are summarized in table 12. Moreover, small tiles were also successfully produced in the laboratories, using again body composition No. IV, pressing, drying and glazing it, and firing it for two hours at 1,225 °C.

It was thus possible to prove that ceramic tableware and tiles can be produced without difficulty, using only local raw materials.

When those newly developed ceramic items were exhibited at the National Fair of Balantyre, great interest was shown in them and a few parties even applied to the Government of Malawi for a manufacturing license for the production of ceramics on an industrial scale. Since there is practically no ceramic industry working on modern lines, except Milandi Pottery, which is producing traditional pottery and handicrafts, utilizing red clays by throwing, there is a great need for technicians and technologists who would run a local ceramic industry. At present, even the University of Malawi does not offer any courses in ceramic technology. Therefore the establishment of a common facility and training centre would greatly improve the situation. Such a centre should have the following functions:

(a) On-the-job training of personnel to run a ceramic industry in Malawi;

(b) Provide facilities for raw material preparation like beneficiation, grinding of soft and hard minerals, body preparation, glaze preparation and firing of ceramic ware;

(c) Provide testing facilities for local ceramic materials and products;

(d) Provide firing facilities (kilns) to private entrepreneurs;

(e) Research and development facilities for the improvement of designs and product quality;

(f) Development of new products from local inorganic, non-metallic oxides for industrial application;

(g) Advisory services for local entrepreneurs regarding their technical problems and guidance in the establishment of a new industry;

(h) Development of kiln designs for the small-scale industry, to improve the firing techniques and increase the kiln output.

The layout of the proposed common facilities centre/pilot plant for ceramics is shown in figure IV. To start, the following equipment would be required:

2 Jaw crushers, 4 t/h

1 Dry grinding plant for soft and hard minerals, 1 t/h (200 mesh) for feldspar and quartz

4 Ball mills, 500 kg, 250 kg, 100 kg, 20 kg

4 Jar mills/pot mills, 10 kg, 5 kg, 2 kg, 1 kg

1 Filtre press, 0.25 t

1 Pug mill, 4", 2", 1" diameter

2 Mixers/grinders (Agate), 20 kg, 10 kg

6 Jigger machines

6 Jolly machines

2 Dryers, up to 200 °C

2 Ovens, 2' x 2' x 2'

2 Kilns, up to 1,400 °C, 4' x 3' x 3'

1 Up-draft kiln, to be built locally (coal and wood-fired)

1 Down-draft kiln, to be built locally (coal and wood-fired)

For the laboratory the following items of equipment are essential:

2 Laboratory furnaces, up to 1,600 °C and 1,450 °C

1 Viscometer

1 M.O.R. apparatus

2 Laboratory ovens, up to 200 °C

1 Microscope (reflected light)

3 Platinum crucibles

Laboratory reagents

At present, Malawi spends millions of kwachas in foreign exchange for the import of various ceramic items, like tableware, tiles, sanitary-ware, technical ceramics, insulators etc. The benefits arising from assisting the country in establishing a ceramic industry based on local raw materials would not only be a saving in foreign exchange, but also an income from exporting the ceramic items to neighbouring countries of the region, besides creating job opportunities for Malawians.

Figure IV. Layout of the proposed common facilities centre/pilot plant