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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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STRENGTHENING OF GOVERNMENT SUPPORT SERVICES IN THE NON-METALLIC MINERALS SECTOR

DP/ZIM/83/006/11-01

ZIMBABWE

Technical report: Testing, classifying and evaluating non-metallic raw materials

Prepared for the Government of Zimbabwe
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of M. Grylicki, expert in
testing, classifying and evaluating non-metallic raw materials

Backstopping officer: H. Yalçindag, Chemical Industries Branch

United Nations Industrial Development Organization
Vienna

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Explanatory notes

The monetary unit in Zimbabwe is the dollar ($Zim).

References to tonnes (t) are to metric tonnes.

Acronyms

AAC	Anglo American Corporation
ASTM	American Society for Testing and Materials
DOM	Department of Metallurgy of the Ministry of Mines, Harare
GS	Department of Geological Survey of the Ministry of Mines, Harare
GW	G & W Industrial Minerals, Harare
IDC	Industrial Development Corporation of Zimbabwe Ltd., Harare
IMR	Institute of Mining Research of the University of Zimbabwe
Lonrho	Lonrho Zimbabwe Ltd.
SACA	Standard Association of Central Africa, Harare
Zimglass	Zimbabwe Glass Industries Ltd., Gweru
Ziscosteel	Zimbabwe Iron and Steel Co. Ltd., Redcliff
ZMDC	Zimbabwe Mining Development Corporation, Harare

Technical abbreviations

CCS	cold crushing strength
Cha	chemical analysis
CIC	creep in compression
DTA	differential thermal analysis
LOI	loss on ignition
MOR	modulus of rupture
MPa	mega pascal
PCE	pyrometric cone equivalent
R & D	research and development
RUL	refractoriness under load
S/S	soluble salts
TDA	thermal dilatometric analysis
TGA	thermal gravimetric analysis
XRD	X-ray diffractometer (or diffractometry)
XRF	X-ray fluorescence spectrometric analysis

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ABSTRACT

Within the context of the large-scale project "Strengthening of government support services in the non-metallic minerals sector" (DP/ZIM/83/006) an expert in testing, classifying and evaluating non-metallic raw materials was assigned to the project for 15 months, from 20 May 1985 to 2 September 1986.

In accordance with his job description, the expert carried out the following tasks: new items of equipment for the testing of mineral raw materials were put into operation, among them for DTA, TGA, TDA and XRD; numerous methods of testing mineral raw materials and finished ceramic products were introduced at the Ceramic Laboratory of the Department of Metallurgy (DOM); the staff of the Laboratory were trained both by lecturing and on-the-job; about 120 samples were tested, among them very valuable ones for the future development of refractories and ceramic industries, such as alumina-bearing (corundum, bauxite, kyanite, fire-clays, kaolins, clays and feldspars) and magnesia-bearing raw materials (magnesites and dunite, which can be used for the manufacture of basic refractories). Samples of good raw materials for the manufacture of glass (limestone, quartz sands) were also evaluated. All test results were compiled on "samples log sheets", available at the Department of Metallurgy.

In addition to his detailed recommendations concerning the use and application of specific tested raw materials for particular products, the expert proposes to set up a research and development centre for non-metallic construction materials at DOM, on the basis of the existing Ceramic Laboratory, outlining its future functions, staffing, equipment and financing.

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INTRODUCTION

The Government of Zimbabwe is aware of the great economical potential of the local non-metallic raw materials. This project stems from the need of creating a systematic approach to the problem of utilizing Zimbabwean non-metallic raw materials. The purpose of the mission of the expert was first of all the creation of a specialized laboratory for the testing of non-metallic raw materials, to furnish it with the necessary equipment, to train the staff in operating the equipment, to introduce relevant methods of testing and to train the staff in the application of these methods, to test available samples for the "Geological Inventory of Zimbabwe" and for the technological part of this project, as well as to select deposits of non-metallic raw materials with a high potential and to test the samples taken from them by all available methods.

Asbestos is not covered by this project, the mining and utilization of which is well developed and has a long tradition in the country.

The activities of the expert began on 21 May 1985 and lasted until 2 September 1986. The main objectives of his mission, as set out in his job description (annex I), were attained.

From the Government's side the project was supervised by the director of the Department of Metallurgy (DOM) of the Ministry of Mines and the national project director, E. Mutowo (B.Sc., M.Sc.). The counterpart staff were:

J. Mapiravana, chemist/geologist, head of the Ceramic Laboratory at DOM
V. Vera, chemical engineer
T. Sanhewe, chemical engineering
N. Maravanyika, geologist
L. Dhliwayo, chemist/analyst
B. Manyau, metallurgist
S. Saungweme, technicien.

During the first 10 months of his assignment (from 23 June 1985 through 11 April 1986) the expert co-operated directly with G. Lenkei, who served as expert in production and technology of ceramics (post 11-02) and as economic adviser (post 11-03).

Vivid co-operation started in December 1985 with the Zimbabwe Mining Development Corporation (ZMDC) on testing samples for the "Geological Inventory of Zimbabwe" (S.M.N. Ncube, divisional geologist at ZMDC) in connection with subcontract No. P85/42 "Preparation of the desk-type inventory study of non-metallic minerals", which lasted until the expert's departure.

RECOMMENDATIONS

1. The development of the non-metallic minerals sector in Zimbabwe should be based, first of all, on the processing alumina-bearing minerals, i.e. corundum, bauxite, kyanite, kaolin, fire-clay, ball clays and flint clays. Mining and upgrading of these raw materials should be further developed.

2. On that basis an aluminosilicate refractories industry should be developed, manufacturing high-duty and super-duty fire-clay refractories, and using refractory clays (Hwange fire-clay, Chiredzi flint clay) and kaolins (Thomson), as well as other high-alumina, mullite and corundum refractories, coming from rich deposits of kyanite and corundum (Ky Mine, Concession).

3. The above-mentioned raw materials, as well as feldspars (Bikita, Borrowdale), which are of the highest quality and occur in large deposits, should be used for the manufacture of almost all types of ceramic whiteware (tableware), sanitary ceramics and technical ceramics (medium-and high-tension electrical insulators).

4. For the sheet-glass industry, which should soon be established, the mining of deposits of pure quartz sands and limestone should be developed.

5. A lime industry, producing calcined unslaked and slaked lime, should be developed as a small-scale industry in rural areas and as a large-scale one, for industrial and construction purposes, based on numerous deposits of limestone in the country.

6. The possibility of using domestic magnesites from the Kadoma and Pande mines (Beitbridge) and dunite from Great Dyke for the manufacture of basic refractories, should be further investigated.

7. The use of local dolimite, after dead burning, for the refractory lining of oxygen convertors at Ziscosteel, should be tried as some dolomites are of very high quality.

8. Technologies for the manufacture of refractory calcium-aluminate cements should be investigated, using Penhalonga bauxite as a source of alumina, and limestone from the Early Worm mine, or from other deposits located close to Harare.

9. A research and development centre for non-metallic construction materials should be set up at the Department of Metallurgy, on the basis of the existing Ceramic Laboratory, its staff and equipment. The centre's main tasks should be:

(a) To continue testing local raw materials and give advice to the industry on their proper applications;

(b) To initiate and pursue co-operation with the industry in implementing technologies for the manufacture of new materials in the field of ceramics, especially refractories, by undertaking related research;

(c) To co-operate with industries using refractories and other ceramic elements (e.g. acid-resistant ceramics) with regard to a proper application of these materials, by giving advice, testing and doing the necessary research;

(d) To analyse current technical literature in the relevant fields and supply the industry with all necessary information;

(e) To co-operate with the University of Zimbabwe in the field of technology of inorganic materials, both in research and in training students;

(f) To co-operate, on the basis of bilateral agreements, with research and development institutes abroad.

10. The Department of Metallurgy should urgently implement the following:

(a) Move sensitive precision equipment such as DTA/TG, dilatometer and colorimeter to another room which is free of vibrations and dust, e.g. to the room adjacent to XRD;

(b) Establish a library or technical documentation unit at DOM, with one permanent librarian having a good knowledge of all technical and scientific problems concerning DOM's fields of activity. Current periodicals, new books, publisher's catalogues of books, manufacturers' catalogues of new equipment, machines, tools etc., should be displayed and there should be a possibility for photocopying. Close co-operation should be established with the libraries at GS, IMR, the University and SACA;

(c) Upgrade the capability of the analytical laboratory by providing it with the necessary reagents, materials (e.g. platinum dishes and crucibles), and in future with some new equipment for instrumental analysis (e.g. XRF);

(d) Ensure that all equipment is supplied with a sufficient amount of spare parts;

(e) Hire an electronic engineer to take care of the equipment containing electronic circuits (XRD, DTA/TG, dilatometer, recorders, furnaces, colorimeter, balances, thermostats etc.);

(f) Upgrade the capabilities of the mechanical and electrical workshops, e.g. to facilitate the manufacture of precise steel dies for pressing shapes or pelletizing ceramic powders under high pressure;

(g) Prepare a suitable space for the existing and the future pilot-plant equipment;

(h) Organize the Ceramic Laboratory along the following lines:

<u>Main tasks</u>

(i) Testing and evaluating non-metallic raw materials and ready-made products (e.g. refractories, all types of ceramics etc.). Co-operation with ZMDC and GS in testing raw materials and with the industry in testing their products;

(ii) R & D in technologies of processing non-metallic raw materials (e.g. kyanite, corundum, bauxite, kaolin, fire-clay, feldspars, bentonite, quartz sands, graphite, dunite, talc, limestone, magnesite, dolomite, vermiculite etc.), their upgrading and the manufacture of various products (e.g. refractories, glass, ceramics, cements etc.);

(iii) R & D in the application of refractories, especially in the iron and steel industry, copper smelters, nickel and cobalt industries, gold smelting furnaces, lime industry, cement kilns, glass industry, ceramic industries etc. (e.g. by preparing a catalogue of users of refractories);

(iv) Development of production of various small ceramic (or refractory) construction elements at DOM, with specific technical properties (e.g. graphite crucibles, small crucibles for induction furnaces, lids, supports, shapes);

(v) Develop new types of ramming mixes by using grog made from calcined kyanite, boulder corundum or silica;

(vi) Develop new types of ramming masses with phosphate bond;

(vii) Research on refractory binders and cements;

Staffing

(i) The main counterpart in the project, J. Mapiravana, should become the head of the Laboratory;

(ii) One person with university education in chemistry should be involved in thermal methods of testing (DTA, TGA and TDA), and in future in heat-conductivity measurements and high-temperature microscopy;

(iii) One person with university education in mineralogy should be involved in optical petrography and XRD (X-ray diffraction phase analysis, mineralogical analysis);

(iv) One person with university education in physical science should be involved in other methods of testing and adapting standard methods (ASTM, BS);

(v) For all above-mentioned methods of testing two technicians should be employed;

(vi) For the technological part of the laborator_, two persons with university education (technology) should be hired, as well as two or three technicians;

Additional equipment

(i) For the laboratory:

- Vibrating ball mill from Retsch, in addition to the existing laboratory sieving machine, to prepare samples for other laboratory tests (ChA, DTA, TGA, TDA, XRD etc.);

- Additional high-temperature laboratory furnace up to 1,700 °C;

- High-temperature microscope up to 1,700 °C;

- Hydrocyclones, diameter 50, 150 and 350 mm;

- Equipment for measurements of PCE of refractories;

- Hot-load testing furnace together with sample drilling machine and precision grinding machine for RUL and CIC testing;

- Petrographic microscope;

- Mercury porosimeter;

- Particle sizer (laser light instrument) for determination of particle size distribution less than 5 μm;

- Hydraulic press for measurement of CCS of refractories, construction ceramics and concretes;

- Device for measurement of thermal conductivity of ceramics and refractories up to 1,000 °C;

- Dilatometer up to 1,650 °C;

- Low-frequency ultrasonic device for non-destructive testing refractory shapes, bricks, blocks, as well as electrical ceramic insulators;

(ii) For the pilot plant:

- Oil-fired or electrically heated chamber furnace up to 1,750 °C;

- Edge runner mill;

- Dry magnetic separator;

- Semi-industrial hydraulic press;

- Jet spray drier;

- Small oil-fired rotary kiln;

(iii) Once the proposed additional equipment has been delivered, introduce at DOM the following additional methods of refractories testing: PCE, RUL, CIC, CCS, porosity distribution, slag resistance, thermal expansion up to 1,650 °C, changes on reheating of refractories, and their non-destructive testing (ultrasonic).

Financing of the Ceramic Laboratory

The activities of the Laboratory, i.e. analysis and testing of raw materials and products, expertise, consultancy, small-scale production, technical information etc., should be performed on a commercial basis, i.e. all services given by the Laboratory should create some measurable income, to cover at least partially the costs of running the equipment (very expensive spare parts and consumables). Some kinds of donations might also be very useful.

11. Close co-operation with the industry, especially on refractories, should be initiated by DOM, by organizing a seminar. The main users of refractories should be advised to prepare short information on:

(a) The types of refractories they use, for what purposes, and their annual consumption and import;

(b) Under which conditions the above-mentioned refractories are working (temperature, type of mechanical and thermal stresses, corrosion);

(c) Which difficulties they encounter.

The manufacturers (Clayproducts and Redcliff Castables) should be asked to give all information on:

(a) The types of refractories they manufacture and the possibility of substituting some of the imported ones;

(b) Possibilities of improving the quality of the manufactured refractories.

The problem of mining non-metallics should be highlighted by ZMDC, based on the results of the "Geological Inventory of Zimbabwe".

The following users of refractories should be invited: Ziscosteel (iron and steel line, coke factory), Bindura Nickel Corporation (nickel smelters and convertors), copper plants (copper smelters and convertors), ferro-chrome and ferro-alloys industries, Portland cement plants (Harare and Bulawayo), tableware and sanitary ceramics (Norbel, Willsgrove Potteries), glass industry (Zimglass), Zimphos, power plants (Hwange, Harare), iron and steel foundries, lime industry (Early Worm), and others.

12. To ensure a continuous successful development of the industries processing non-metallic raw materials, future activities in this area should be supported by a new UNDP/UNIDO project "Strengthening of technical advisory capabilities for non-metallic mineral based industries".

I. ACTIVITIES

A. Assessment of reports on local raw materials

As set out in his job description (annex I), the expert first studied all reports relating to the activities of UNIDO in this sector in Zimbabwe, a list of which is reproduced as annex II. Among these were: Cohen's report on kyanite, Vlajcic's and Budimir's report on magnesite and Engeltaler's as well as Zika's reports. Morrison's reports give broad information on alumina-bearing minerals, whereas Warner, Barlow, and Phaup deal with all possible minerals, which were found during geological exploration in Zimbabwe. The annual report for 1958 contains interesting information on the output of minerals of industrial value.

On the basis of the gathered information the expert prepared a list of rocks and minerals, deposits of which were found in Zimbabwe, and which may or might have an industrial application as non-metallic raw materials (see annex III). These are mainly alumina and aluminosilicate minerals. It was suggested to test at least some of them for the preparation of the "Geological Inventory of Zimbabwe".

Based on the information obtained from ZMDC on possible reserves of non-metallic minerals in Zimbabwe (see annex IV) and with a view to an immediate application of these types of raw materials, the expert suggested to give first priority in testing to the following: corundum (boulder and crystalline), bauxite, kyanite, fire-clays (flint and ball type), kaolins, feldspars, montmorillonite (bentonite), vermiculite, talc, diatomaceous earth, perlite, magnesite, dolomite and calcite (limestone). Some other raw materials, like asbestos, were not taken into account as their mining and application has been very well developed for many years in Zimbabwe. Minerals like gibbsite, andalusite, halloysite, illites, tridymite, gypsum or native sulphur have not been found in considerable quantities. Very interesting from the technological and economical point of view might be the occurrences of mineral zircon ($ZrSiO_4$). Possible reserves of it in Zimbabwe are estimated on 100 million tonnes. However, no precise data could be obtained.

There are numerous domestic raw materials, some of them already mined and available on the local market, while deposits of others are known to geologists but are not yet well estimated.

Of major importance for the development of a ceramic industry, especially of a refractories industry, are the deposits of minerals the chemical composition of which embraces basically the two component system Al_2O_3-SiO_2 (with some admixtures and contaminants). There are deposits of corundum (Concession - O'Briens, Belingwe, Andrew Claims), diaspore (72-80 % Al_2O_3) (seven deposits in the south-eastern lowveld and near Hwange), kyanite (58-62 % Al_2O_3) (Karoi, Mutoko), bauxites (40-48 % Al_2O_3) (Penhalonga, at the border to Mozambique), flint clays (34-39 % Al_2O_3) (Chiredzi, Chivumburu), Kaolins (24-37 % Al_2O_3) (Kadoma, Thompson, Bude Farm,), fire-clays and ball clays (24-37 % Al_2O_3) (Gwaai, Hwange, Beitbridge), numerous local brick clays and further: diatomites (Zambezi valley), quartzite (Hwange), quartz (Gweru) and pure quartz sand (up to 99.3 % SiO_2). There are also rich deposites of feldspars (Misstress, Bikita) and vermiculite (Mutoko), as well as lithium aluminosilicates. The above-mentioned raw materials are suitable for the manufacture of a wide variety of valuable ceramics, starting from very expensive corundum or high-alumina refractories, all kinds of porcelain wares, sanitary wares, earthen-ware pipes, wall and floor tiles, mosaic tiles to building bricks and electrical porcelain. Some of them, e.g. diaspore or bauxite, are suitable for the manufacture of high-alumina refractory cements, others (quartz sands) as a component for glass manufacture.

There are also deposits of limestones, dolomites and magnesites in Zimbabwe, which, unfortunately, up to now have played a comparatively minor role, because large quantities of lime are still being imported.

Graphite, deposits of which are near Kariba Lake, could be useful in the development of a refractories industry (graphite crucibles, graphite blocks and shapes).

B. Equipment for testing of and researching on non-metallic raw materials

When the expert arrived at the Department of Metallurgy he found the following equipment (see also list in annex V), still packed in boxes:

1. Colorimeter, model Tricolor FLFM3, Dr. Lange. This machine was damaged during transport. The damaged part, the cabinet, was replaced by the manufacturer and the expert repaired the equipment.

2. High-pressure autoclave, type 6983 (251), Tonitechnik, 25 dm^3; 3.5 MPa; 250 °C. The autoclave was ordered and delivered without counterweight. The missing part, which was designed and made in the mechanical workshop of DOM and enables an easy lifting of the cover lid.

3. Torsion viscometer, model RVT, Brookfield, with spindle set (minimum viscosity 0.1 Pa.s; maximum 8 x 10^5 Pa.s).

4. Laboratory sieving machine, type Vibro, Retsch, with screens of 0.200, 0.180, 0.160, 0.125 and 0.100 mm.

5. Ultrasonic sieving apparatus, type USG, Retsch, with precision sieves of 100, 80, 70, 60 50, 40, 30, 20, 10 and 5 µm for precise grain size analysis of non-plastic powders of solid materials in water (or other liquids) suspensions. Since this apparatus could have very limited application in the envisaged tests, the additional ordering of Andreasen pipettes was proposed. These are suitable for routine, standard particle-size analysis, especially of clays in water suspension, down to 2 µm.

6. Simultaneous TGA/DTA instrument, type 409, Netzsch, for maximum 1,350 °C.

7. Electronic dilatometer (for TDA), type 402E/2, Netzsch, for maximum 1,340 °C.

   The TGA/DTA instrument and the dilatometer have one common transformer, one controller and one recorder. This means that simultaneous testing by DTA/TGA and TDA cannot be performed. It was apparent from the beginning that the third channel of the recorder for DTA was not working properly. Strong variations affected the width of a DTA curve. After extensive correspondence with the manufcturer, Netzsch, the expert successfully repaired the recorder.

8. Bending strength tester, model 401, Netzsch, for maximum 600 N.

9. Heating bath and circulator, type 000-5699, Haake. This machine was delivered by Netzsch together with DTA/TGA and TDA equipment in order to keep the cold part of the equipment (mainly thermo-elements) at room temperature.

10. Electrically heated gradient furnace, model G100/g, Naber; length of chamber 1,000 mm; $\Delta T = 300$ K, maximum temperature 1,340 °C.

11. Electrically heated high-temperature laboratory furnace, model HTO 8/17, Naber; with superkanthal ($MoSi_2$) heating elements for maximum 1,700 °C), with small heating chamber.

12. Drum-type wet grinding mill (ball mill), type BGAK/SE, volume 100 dm^3, with alumina balls, from H. Welte. This machine has been regarded as part of the future pilot plant equipment.

13. JB two-tier de-airing pugmill (vacuum extruder), driven by 2.2 kW motor, from Edwards & Jones Ltd. This machine was also delivered for the pilot plant.

14. Screw-type filter press, 15 chambers size 0, screen type 3, from Boulton Ltd; also designed for the future pilot plant.

In October 1985 the last item from the primary list of the ordered equipment was received, namely:

15. Run-through ferro filter (wet magnetic separator for de-ironing slips), model 41, with rectifier, from Franz Co., also for pilot plant purposes.

In January 1986 two additionally ordered pieces of laboratory equipment were delivered:

16. Plasticity tester, design Pfefferkorn, from Tonitechnik, for measurements of plasticity of clays.

17. Spectral pyrometer Optix, type PB 05 AF2 (750-2,000 °C) from Keller Pyro.

At the end of April 1986 the next three additional items of equipment were delivered:

18. Moisture determination balance, model Thermoray (infra-red principle) from ALS, Milano.

19. Thermostat Regaterm, model RT 1000, from ALS, Milano, for keeping a constant temperature during measurements of particle sizes by the sedimentation method, viscosity measurements of slips, density measurements, as well as measurements of water vapour adsorption of clays.

20. Andreasen glass apparatus (two pieces) for routine determination of particle size of fine grained materials, from ALS, Milano.

On 6 June 1986 the following important instruments were received, which were ordered in November 1985:

21. X-ray diffractometer, consisting of X-ray generator model Kristalloflex 710, with X-ray tube type FK 60 Cu 04, diffractometer model D501, recorder Kompensograph XI, spinner, spare X-ray tube, sets of spare parts for the generator and the diffractometer, all from Siemens.

22. Carver laboratory hydraulic press, model C12, capacity 10 tonnes from ALS, Milano.

23. Abrasimeter, model Cesconi, manufactured by ALS, Milano.

The expert unpacked, assembled, checked and put into operation all of the above equipment, except the pugmill (13) and the filter press (14) which were put into operation by the expert in technology and production of ceramics, G. Lenkei. The X-ray diffractometer was unpacked, assembled and put into operation on 26 June by a specialist from Siemens.

For the high-pressure autoclave (2), the DTA/TGA (6), and for the gradient furnace (11) the expert prepared detailed operating instructions in written form. In the operation of all other equipment, the counterpart staff were trained on-the-job according to manufacturers' instructions supplied with each piece of equipment.

Finally, it should be mentioned that a new laboratory furnace was designed and constructed under this project from locally available parts:

24. Electrically heated chamber furnace (300 x 220 x 550 mm) with 6 Globar heating elements, for temperatures up tp 1,200 °C.

C. Testing methods

Based on the available equipment, the following standard methods for the testing of non-metallic raw materials, ceramics and refractories, have been introduced at the Ceramic Laboratory at DOM:

(a) DTA up to 1,300 °C, to measure thermal effects on a sample. The method is suitable for all materials in which heating or cooling causes any chemical reaction, polymorphic transformation or other physical phenomenon (desorption, evaporation, relaxation). Although the equipment allows to set various values for measuring parameters, the expert proposed to use the following as standard ones: heating rate 1 °K/min; DTA recorder span 0.2mV; furnace parameters $Xp = 5$, $T_n = 5$; chart speed 120 mm/h;

(b) TGA up to 1,300 °C to measure the change of mass of a tested sample. It can be applied to such materials in which any chemical reaction (oxidation, reduction, decomposition e.g. $CaCO_3 = CaO + CO_2$ etc.) takes place or a physical process occurs (evaporation, sublimation), connected with a change of the mass. As DTA and TGA are in principle simultaneous, the proposed standard parameters are similar to those for DTA. However, the precise TGA measurement should be adapted to the expected change of a mass;

(c) TDA on heating up to 1,300 °C and on cooling, based on the measurement of the characteristic changes in linear expansion or contraction at specific temperatures. This method is suitable to indicate all chemical reactions, polymorphic transformations, and some other physical processes, such as sintering, in a tested sample. In the case of TDA the proposed standard heating rate is 5 °K/min. Furnace parameters and chart speed are the same as for DTA/TGA;

(d) Mineralogical analysis, based on the identification and determination of crystalline phases in raw materials and products by means of XRD phase analysis. In this case powder diffraction methods were applied, with CuK alpha radiation (Ni filtered). This is the most versatile and reliable method for mineralogical analyses, first of all qualitatively, but in some cases a semi-quantitative or even quantitative determination of crystalline phases is possible.

For the interpretation of DTA data, the book Thermal Techniques by R.J.W. McLaughlin (available at the University of Zimbabwe) and for the interpretation of TGA and TDA results, Applied Clay Mineralogy by R. E. Grim (available at GS Library) were recommended by the expert. For the identification of minerals, DOM has been provided with a special "Mineral powder diffraction file search manual", and "Mineral file workbook". In this way all interpretation of XRD diagrams can be performed on the spot;

(e) Determination of the linear expansion coefficient between 20 °C and 1,300 °C of ceramic bodies, and between 20 °C and 600 °C of ceramic glasses and glazes by means of the TDA apparatus. The parameters are the same as for TDA. The expert prepared the correction curve for the equipment and trained the staff in testing and calculating the thermal expansion coefficient;

(f) Determination of viscosity and thixotropy index of ceramic slips. For this purpose Brookfield's torsion viscometer is used. The expert gave six hours of lectures on the problems of viscosity measurements of non-Newtonian liquids and prepared a written hand-out of five pages. All counterpart staff were trained on-the-job. For keeping constant temperature of measured slips, the thermostat (item 19) should be used. At the expert's request DOM was supplied by the manufacturer with a set of literature on viscosity measurement;

(g) Grain size distribution of powders in the range between 200 and 53 μm by means of the laboratory sieving machine, and the set of sieves (item 4);

(h) Bending strength determination of green and fired ceramic bodies by means of the bending strength tester (item 8). The staff received on-the-job training in performing the tests and calculating the strength of tested bodies. The expert also demonstrated the principles of modulus of elasticity measurements. However, since for that purpose exactly, rectangular samples have to be prepared, it was decided not to introduce this type of measurement in the Ceramic Laboratory of DOM, firstly because of the difficulties in preparing proper samples and secondly, because the cases when such testing might be advisable would be very rare;

(i) Degree of whiteness and colour measurements of fired ceramic bodies, some raw materials (also in powdered form) and slips. The counterpart staff were trained on-the-job, using the manufacturer's instructions (Dr. Lange). Because of the high efficiency of the equipment, the measurements are fast and easy to perform. The equipment has found wide application in fine-ceramics testing;

(j) Plasticity testing of clays by Pfefferkorn method. Although the method itself is not regarded as standard it has very wide application in plasticity testing because of its relative simplicity. The staff were trained on-the-job;

(k) Behaviour of some ceramic products under high-pressure water vapour (the autoclave method). The expert prepared additional, detailed operating instructions for the proper handling of the autoclave, because the ones provided by the manufacturer were not sufficient. The autoclave has been adapted for craze resistance tests of wall tiles and tableware. The tests were performed under pressure up tp 630 kPa, according to the British Standards (available at SACA);

(l) Linear change measurements on drying and on firing (shrinkage) of ceramic bodies and raw materials, and sinterability of some refractory raw materials by means of the high-temperature laboratory furnace (up tp 1,650 °C) or the gradient furnace (up tp 1,300 °C) have found very wide applications in the testing of ceramics and refractories (see ASTM Standards Vol. 17/1982, available at IMR and SACA). After on-the-job training, the counterpart staff have been performing numerous tests of this kind;

(m) The simple "pellet method" of refractories corrosion testing has been adapted. It was applied for corrosion resistance testing of refractory ramming masses for lining gold smelting furnaces;

(n) Measurement of moisture content in clays and ceramic masses on samples irradiated by infrared rays (fast-balance method). This method is very simple and the staff were trained on-the-job;

(o) Particle-size measurements of clays and ceramic slips between 60 and 2 μm by the Andreasen method (sedimentation principle). The measurements have been performed according to the "Standard methods of testing No. 2, Andreasen pipette method" from the British Institute of Ceramics. The brochure is in the possession of DOM;

(p) Measurement of true and apparent porosity, density, and apparent density by water soaking and hydrostatic measurements. The staff were trained on-the-job. The Ceramic Laboratory has been provided for this purpose with the brochure "Standard methods of testing No. 7: The measurement of true and apparent porosity and percentage closed pores" from the British Institute of Ceramics;

(q) Soluble salts determination by boiling a powdered sample in distilled water;

(r) Water vapour adsorption of clays. After drying at 110 °C to the constant weight, the clay sample is put into a dessicator over a saturated solution of NaCl in water, and the gain of mass, caused by water adsorption in the sample, is measured after 48 hours;

(s) For the measurement of the exfoliation ability of vermiculite and the expansion coefficient of perlite on heating, a simple method has been adopted: a raw sample, placed in a crucible, is put into the chamber furnace and heated to 90 °C. The bulk density of the charge is compared before and after heat treatment;

(t) Chemical analyses of non-metallic raw materials and products has been performed at the Chemical Laboratory at DOM for many years. The Laboratory has proper equipment, skilled staff and long experience in analytical chemistry;

(u) Petrographic microscopy has been applied at DOM only to a very limited extent, because of the lack of proper equipment. Thin sections were prepared at GS, and only morphological and textural observations were made in some cases;

(v) Semi-quantitative spectrographic analysis has been performed at GS by means of an old spectrograph of the Q24 type on some samples as a source of additional information on their chemical composition;

(w) For testing clays and kaolins, complex methods of testing have been applied. Besides routine tests like ChA (t), DTA (a), TGA (b) and XRD (d) the following have been used: particle size analysis (o), rheological tests of slips with and without defluocculants (f), casting rate of slips to plaster moulds, plasticity measurements (j). For further unfired properties: colour co-ordinates (i), extrusion moisture content, critical moisture content, linear drying contraction (l), modulus of rupture (by bending) of test pieces, extruded and dried at 110 °C (h). For fired properties (after firing test pieces at 1,100, 1,200 and 1,300 °C): linear shrinkage (l), open porosity (p) and bulk density, modulus of rupture (h), and colour co-ordinates (i). All results have been recorded on a "Sample log sheet";

(x) With the laboratory hydraulic press (see item 22) with an operational capacity of 10 tonnes, CCS can be measured under two conditions: if the tested sample is mechanically not very strong and if its cross section is not large. For example, if a sample has a standard circular cross section of 30 mm diameter the applied pressure must not be higher than 15 MPa. However, the press can be used for pressing small pellets. To press a 15-mm diameter pellet, up to 62 MPa can be applied;

(y) Abrasion resistance of ceramic (or refractory) material can be determined by the Cesconi abrasimeter (see item 23). For this kind of determination samples should be cut to fit the shape of the holder, or be put into resin and formed to the proper shape. This type of test is important for some ready-made ceramic materials or refractories.

All methods based on application of the pilot-plant equipment were adapted by the expert in production and technology of ceramics (post 11-02).

D. Training of counterparts

The main effort was put on the on-the-job training of the counterpart staff, first of all in the proper operation and maintenance of the equipment and in testing methods of non-metallic raw materials. For that purpose the expert elaborated additional operation instruction for the autoclave, the DTA/TGA equipment and the gradient furnace.

The expert also prepared and gave lectures on more complex methods of testing, namely:

(a) Thermal methods (DTA, TGA, TDA);

(b) Rheology of non-Newtonian liquids (viscosity);

(c) XRD-phase analysis (mineralogical analysis).

It was also found highly advisable to give lectures on the background of the technology of ceramics and refractories, theoretical and applied, as well as on the processing of non-metallic mineral raw materials. The lectures, altogether 40 hours, were prepared by the expert and delivered between 15 January and 20 May 1986 (see annex V). Seventeen pages of handouts were typed and distributed to the counterpart staff.

Proposals for fellowship training of the project's counterparts were worked out and submitted to the national project co-ordinator.

E. Technical and scientific information

DOM has no properly functioning library. There is, however, one room in which some old books and journals are stored. Up to the arrival of the expert practically no books on the processing of non-metallics or on ceramics were available in that library. The expert subsequently suggested to UNIDO to order some journals on ceramics and to buy some books that would be useful in the current work of the Ceramic Laboratory. In 1985 DOM began to receive the following journals: Industrial Minerals, Journal of the American Ceramic Society, Bulletin of the American Ceramic Society, Ceramic Abstracts and British Ceramic Transactions and Journal. From among 45 titles of scientific and technical books, which the expert proposed to UNIDO to order, DOM obtained 24 titles, among them seven booklets on standard methods of testing. From the budget authorized for local purchase, the expert bought at Harare 12 technical books related to the objectives of the project. That way the library at DOM received altogether 36 books and five periodicals, in addition to which the expert obtained, on request, free copies of numerous articles (e.g. on viscosity measurement), brochures on equipment and one free periodical, International Laboratory.

The library at GS, with which DOM co-operates, is well organized and directed mainly towards geology. There are some books on clays and optical petrography, which may be of some use at DOM. Unfortunately, the library at GS has, for many years, not been supplied with new books on topics of interest to DOM.

The library at IMR possesses a number of interesting books, among them some on mineralogical analysis, on XRD, and a few books on ceramics. The library is supplied from time to time with books granted by the British Council. Numerous books are on a permanent loan from the Main Library of the University of Zimbabwe. However, there is some difficulty in using that library, because the catalogue is arranged in alphabetical order by the first letter of the title of the book.

The Main Library of the University of Zimbabwe can be regarded as a top level library. Many books on interesting topics are available, among them on ceramics, on XRD, on non-metallic raw materials etc. The Library is supplied with many periodicals on various topics, among them almost all periodicals on ceramics. There are very good author's and subject catalogues of books, as well as catalogues of all periodicals. It is possible to use the books and periodicals on an interlibrarian lending basis.

The library at CASA possesses all updated British Standards as well as standards of the American Society for Testing and Materials. CASA is very well equipped and one can buy copies of the standards. CASA is located in the vicinity of DOM.

F. Co-operation with the industry

The expert visited the following plants, whose activities are connected with the application of non-metallic mineral raw materials, either as a component of their products or as a part in the construction of furnaces, kilns or other equipment:

(a) G & W Industrial Minerals at Harare - upgrading some non-metallic raw materials mainly by crushing, milling and grain size classification. There are no facilities for the processing of raw materials at high temperatures (e.g. calcining magnesite);

(b) Morbel Potteries at Harare - manufacture of tableware. They use refractory lining for their furnaces, as well as so-called kiln furniture (supports, plates, casings, boxes etc.). The kiln furniture is made from high-alumina ceramics, sometimes with cordierite bond. Casings are manufactured from carborundum-containing ceramics;

(c) Mosaic Tiles (Stuart) at Harare - manufacture of wall tiles. Tests of ready-made tiles on "crazing" were performed at DOM by the autoclave method;

(d) Earthenfire (Graham Davies) at Harare - manufacture of mainly wall tiles. Tiles were tested at DOM under various conditions in the autoclave. Numerous tests on thermal expansion of ceramic bodies and glazes were also performed;

(e) ALFA Bricks (Mount Hampden Brickworks) close to Harare - manufacture of building bricks and floor tiles. The local brick clays were tested at DOM and found suitable for the manufacture of wall tiles. The expert suggested that the bricks or tiles from Mount Hampden should be tried for acid-resistant constructions;

(f) Zimphos at Harare - manufacture of sulphuric acid, phosphoric acid and phosphate fertilizers. Acid-resistant ceramics are used as a construction material in various parts of the plant. One of the products of Zimphos, phosphoric acid, finds an application as a binder in refractory ceramics;

(g) Circle Cement at Harare - manufacture of Portland cement and agricultural lime (byproduct). All refractory lining for two rotary kilns is imported. The expert pointed out that some of the imported material can be substituted by the locally made refractories from Clayproducts at Bulawayo;

(h) Zimglass at Gweru - manufacture of glass containers. They do not encounter any problems with refractories, although all are imported, because their electric kilns are relined every three years and for that purpose special melt-casted refractory blocks are used. However, they import 20,000 tonnes of calcite every year, and in the expert's opinion this situation should be rectified as soon as possible, because there are deposits of calcite in Zimbabwe. All other raw materials for glass manufacture are local (except sodium carbonate). Plans exist to develop in the near future the manufacture of frits and glazes for the ceramic industry;

(i) Willsgrove at Bulawayo - manufacture of tableware and wall and floor tiles. The production is based entirely on their own local deposits of raw materials. The only items which are imported are glazes and refractories;

(j) Trojan Bindura Nickel Co. at Bindura - processing nickel and cobalt ore, manufacturing metallic nickel. All refractories for the lining of mixers, converters and electric arc furnaces are imported. Some of them could be substituted by locally manufactured refractories;

(k) Redcliff Castables at Redcliff. This is a small factory manufacturing refractory grog, ramming mixes and castables, mainly from used recycled high-alumina bricks and shapes, as well as chrome-magnesia and magnesia bricks and shapes from Ziscosteel and imported refractory alumina cements "Cement Fondu", "Secar 70" and "Secar 80". Besides, they manufacture aluminosilicate crucibles, which are phosphate bonded. The only component imported for this purpose is andalusite, which in future can be replaced by local calcined kyanite;

(l) Clayproducts at Bulawayo. Their main products (70% of annual value) are aluminosilicate refractories, mainly of normal-duty quality: bricks, various types and shapes, among them special shapes (e.g. suspended tiles, springer blocks, funnels, runners etc.), as well as normal-duty fire-clay. For the manufacture of these refractories Chiredzi flint clay, Hwange fire-clay and Gwaai clay are used. They manufacture also so-called "clay-cast" shapes or refractory concrete shapes, containing fire-clay grog and as a binder high-alumina refractory cement (either "Cement Fondu" or "Secar 70"). The high-alumina refractory cements are being imported. Following the expert's suggestion, a trial on the application of boulder corundum from Concession Mine as a high-quality grog has been started;

(m) Ziscosteel at Redcliff - the main consumer of refractories in Zimbabwe: aluminosilicate, high-alumina, magnesite, chrome-magnesite and silica refractories. Except normal-duty fire-clay refractories (from Clayproducts) all others are imported. The management of the steel plant requested the expert to help in solving the problem of spalling the runners from Clayproducts during steel casting;

(n) Lonrho Gold Smelting Plant at Harare. The writer was asked to help in solving the problem of easy corrosion of the refractory lining of gold smelters, because recently applied ramming mix "Redcast 1600", manufactured by Redcliff Castables, used as a substitute for earlier imported andalusite-mix did not behave so well during service. The expert advised Lonrho to use mixes composed of kyanite calcined at 1,450 °C and plastic fire-clay as a binder, or calcined boulder corundum grog and plastic fire-clay.

At DOM the expert gave advice on the manufacture of graphite crucibles and prepared a two-page instruction for this purpose.

G. Tested samples

At the beginning some laboratory tests were performed on samples available at that time, coming mainly from G & W as commercial samples (samples No. 109-111, 120-122 and 124 in the following table) and a few others delivered by individual enterpreneurs. On 3 December 1985 co-operation with ZMDC started on the "Geological Inventory of Zimbabwe" under subcontract No. P85/42, and more than 100 samples of various non-metallic raw materials were delivered by ZMDC for testing. For the compilation of the various data and test results, special "Sample log sheets" were prepared at DOM, on which all details were entered. The tested samples and the method applied are given in the following list.

Samples of non-metallic mineral materials and methods of testing them

Sample No.	Material	Method of testing a/ a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
1	Corundum (boulder - Concession)			+	+	b/												–	b/		+	–	–				
2	Bauxite (Penhalonga)	+	+		+																+						
3	Bauxite (Bulawayo)	+	+	–	+		–		–		–		–			–			–		+			–			
4	Garnet				–												–				+						
5	Bentonite (Zamudio)	+	+		+														+		+			–			
6	Spodumene (Bikita)	–	–		–																+		–				
7	Lepidolite (Bikita)	–	–		–																–		–				
8	Amblygonite (Bikita)				–																+		–				
9	Petalite (Bikita)				–																+		–				
10	Pollucite (Bikita)				–																+		–				
11	Feldspar (Bikita)				–																+						
12	Fire-clay (Hwange-drilling) I	+	+	–	+		–		–	+	–		–			–		+	–		+			–			
13	Fire-clay (Hwange-drilling) II	+	+	–	+		–		–	+	–		–			–		+	–		+			–			
14	Fire-clay (Hwange-drilling) III	+	+	–	+		–		–	+	–		–			–		+	–		+			–			
15	Barite (Guruve)				–					–							–				+	–	–				
16	Flyash (Hwange Power Plant)	+	+		–			–													+						
17	Calcite (Nyamapanda)	+	+		+																+	–	–				
18	Dolomite (Rushinga)	–	–		–																+	–	–				
19	Kaolin (Chakari)	+	+		–				–	–	–		–			–	–	+			+			–			
20	Limestone (Early Worm)	–	–		–																+	–	–				

continued

Sample No.	Material	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
		Method of testing a/																									
21	Magnesite (Kadoma)	-	-		-																+	-	-				
22	Talc (Kwekwe)	-	-		-																+	-	-				
23	Feldspar (Borrowdale)				-																+						
24	Vermiculite (Nyazura)	+	+		-															-	+						
25	Ball Clay (Beitbridge)	+	+	+	+		+		+	+	+		+			+	+	+			+			+			
26	Sericite (Mt. Darwin)	-	-		-																-		-				
27	Fluorspar (Chiredzi)				-												-				+		-				
28	Flint clay (Chiredzi)	+	+	+	+	+			+	+	-		+				+	+			+			+			
29	Graphitic pyrophyllite	+	+		+																+	-	-				
30	Impure talc (Philabusi)	-	-		-																+	-	-				
31	Magnesite (Beitbridge)	+	+		-																+	-	-				
32	Clay (Rutendo)	-	-	-	-		-		-	-	-		-			-	-	-			+			-			
33	Diatomaceous earth (Chemutsi)	+	+		+																+		-				
34	Lonrho ramming mixes	+	+		+			+					+	+			+				+						
35	Runner bricks from Ziscosteel	+	+	+	+	+							+				+				+	+					
36	Corundum (Beitbridge)																-				+		-				
37	Epidote (Beitbridge)	-	-		-																+						
38	Garnet (Beitbridge)				-												-				+						
39	Unakite (Beitbridge)	-	-		-																+						
40	Fluorite (Beitbridge)				-																+		-				
41	Montmorillonite (Gwanda)	-	-		-														-		+						

continued

Sample No.	Material	Method of testing a/																									
		a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
42	Perlite (Beitbridge)	+	+		+															−	+						
43	Kyanite (Ky Mine)				−								+				+				+	−					
44	Rough quartz (Mistress)																				+	−					
45	Petalite (Mistress)				−																+						
46	Feldspar (Mistress)				−																+						
47	Crystalline limestone (Bombodza) I	+	+		+																+	−					
48	Crystalline limestone (Bombodza) II	+	+		+																+	−					
49	Crystalline limestone (Bombodza) III	+	+		+																+	−					
50	Quartz (rough) (TOT) I																				+	−					
51	Quartz (rough) (TOT) I																				+	−					
52	Coarsy crystalline calcite (Rogo) I	+	+		+																+	−					
53	Coarsy crystalline calcite (Rogo) II	+	+		+																+	−					
54	Coarsy crystalline calcite (Rogo) III	+	+		+																+	−					
55	Vermiculite (Ky Mine)	+	+		−															−	+						
56	Kyanite (Ky Mine)				−								−				−				+						
57	Kyanite + vermiculite + corundum (Ky) I	−	−		−																+	−					
58	Kyanite + vermiculite + corundum (Ky) II	−	−		−																+	−					
59	Kyanite (Dewera)				−								−				−				+						
60	Graphite (Lynx) I	−	−		−																−	−	−				
61	Graphite (Lynx) II	−	−		−																−	−	−				
62	Mica (Hendren)	−	−		−																−						
63	Mica (Kierie) I	−	−		−																−						
64	Mica (Kierie) II	−	−		−																−						

continued

Sample No.	Material	Method of testing a/																									
		a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
65	Dolomite (Gundi) I	+	+		+																+	-	-				
66	Dolomite (Gundi) II	+	+		+																+	-	-				
67	Dolomite (Gundi) III	+	+		+																+	-	-				
68	Dolomite (Alaska) I	+	+		+																+	-	-				
69	Dolomite (Alaska) II	+	+		+																+	-	-				
70	Dolomite (Alaska) III	+	+		+																+	-	-				
71	Dolomite (Alaska) IV	+	+		+																+	-	-				
72	Dolomite (Gundi Park) I	+	+		+																+	-	-				
73	Dolomite (Gundi Park) II	+	+		+																+	-	-				
74	Dolomite (Gundi Park) III	+	+		+																+	-	-				
75	Kaolin (Carn Brae)	+	+	+	+		-		-	-	-		-			-	-	-			+			-			
76	Felsic kaolin (Carn Brae)	+	+	+	+		-	-	-	-	-		-			-	-	-			+			-			
77	Verdite/epidote (Concession)	+	+		+																+						
78	Talc/kaolin (Concession)	+	+	+	+		-	-	-	-	-		-			-	-	-			+			-			
79	Corundum (Concession)			+	-												-				+	-	-				
80	Quartz (rough) (Slam 3) I																				+	-					
81	Quartz (rough) (Slam 3) II																				+	-					
82	Baryte (Dodge) I				-					-											-	-					
83	Baryte (Dodge) II				-					-											-	-					
84	Quartz crystals (Ulva Farm) I																				-		-				
85	Quartz crystals (Ulva Farm) II																				-		-				
86	Quartz crystals (Ulva Farm) III																				-		-				
87	Talc (Wadzanai) I	+	+		+																+		-				

continued

Sample No.	Material	Method of testing a/																									
		a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
88	Talc (Wadzanai) II	+	+		+																+		-				
89	Apatite (Dorowa) I				-																+	-	-				
90	Vermiculite (Dorowa) I	-	-		-															-	+						
91	Apatite (Dorowa) II				-																+	-	-				
92	Vermiculite (Dorowa) II	-	-		-															-	+						
93	Feldspar (microline) Bikita I				-																+						
94	Feldspar (microline) Bikita II				-																+						
95	Feldspar (microline) Bikita III				-																+						
96	Limestone (Houghton) I	+	+		+																+	-					
97	Limestone (Houghton) II	+	+		+																+	-					
98	Quartzite (Mushandike - Sebakwe)																				+	-					
99	Baryte (Argosy)				-					-							-				+						
100	Limestone (Falcon lime)	+	+		+																+	-					
101	Quartzite (felsite) (Rhomet) I																				-	-					
102	Quartzite (felsite) (Rhomet) II																				-	-					
103	Primary kaolin (Chiredzi)	+	+	+	+		-	-	-	-	-		-			-	-	-			+			-			
104	Weathered basalt (Chiredzi)	+	+		+																+						
105	Serpentine (verdite) (Great Dyke)	+	+		-																+	-					
106	Nepheline - syenite (Marangudzi)				-																+	-					
107	Dunite (Great Dyke)				-																+	-					
108	Serpentinized dunite (Great Dyke)				-																+	-					
109	Fire-clay (Hwange)	+	+	+	+		+	+	+		+		+			+		+	+		+			+			

continued

Sample No.	Material	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
		Method of testing a/																									
110	Clay (Gwaai)	+	+	+	+		+	+	+		+		+			+		+	+		+			+			
111	Zimbabwe Thompson Kaolin	+	+	+	+		+	+	+	+	+					+		+	+		+			+			
112	Kaolinitic clay from Cernol Chemicals	+	+	-																	+						
113	Brick clay (Mt. Hampden) - grey	+	+	+	-		+	+	+		+		+			+		+	+		+			+			
114	Brick clay (Mt. Hampden) - red	+	+	+	-		+	+	+		+		+			+		+	+		+			+			
115	Brick clay (Mt. Hampden) - average	+	+	+	-		+	+	+		+		+			+		+	+		+			+			
116	Brick clay (Mt. Hampden) - green	+	+	+	-		+	+	+		+		+			+		+	+		+			+			
117	Brick clay (Broomberg)	+	+		+																+						
118	Talc (Cernol Chemicals)	+	+		+																+						
119	Kaolin (Penhalonga)	+	+		+																+						
120	Vermiculite (G & W)																			+	+						
121	Dolomite (G & W)	+	+		+																+						
122	Bentonite from Tanzania (G & W)	+	+		+																+						
123	Kaolin (Zamudio)	+	+	+	+		+	+	+		+		+			+		+	+		+			+			
124	Ball clay from Tanzania (G & W)	+	+	+	+		+	+	+		+		+			+		+	+		+			+			

a/ The lower-case letters refer to the method of testing described in section C above.

b/ The symbol (+) means that the test was done, (-) that the test is to be performed.

II. CONCLUSIONS

A. Samples of non-metallic mineral raw materials

Alumina minerals

Corundum

Two different samples of corundum were tested: crystal corundum from the Beitbridge region (sample 36) and micro-crystalline boulder corundum from the Concession Mine (samples 1 and 79). Boulder corundum, which has been mined for many years, is of greater importance for its wider industrial application. The tested samples contained 84.4% Al_2O_3 and 3.8% TiO_2, only 2.8% SiO_2, 2.9% Fe_2O_3, a few per cent of Cr_2O_3 and minor amounts of CaO, MgO and K_2O. A piece cut from the uniform sample had the same thermal expansion coefficient as polycrystalline corundum ceramics up to the testing temperature of 1,250 °C. Another sample did not show either permanent linear changes or melted edges after firing it up to 1,500 °C. Extensive information on corundum in Zimbabwe was published by E. R. Morrison in 1972 (see annex II).

Taking into account the properties of the above samples, the expert suggests that boulder corundum from Concession (samples 1 and 79) should be used as refractory grog for the manufacture of high-duty and super-duty refractories and ramming mixes. It would be advisable to calcine lumps of corundum at temperatures up to 1,250 °C and to select uniform, not melted pieces for further processing.

Kyanite

Three samples of kyanite from two different deposits were tested: two from the existing mine at Ky (samples 43 and 56) and another one from Dewera (sample 59). The samples from Ky Mine are of a very high quality. They contained 61.3% Al_2O_3, 37.5% SiO_2, 0.6% Fe_2O_3, 0.2% MgO and only traces of alkalis. During transformation tests it was found that after firing at 1,350 °C the density was 3.05 g/cm^3, after 1,400 °C 3.02 g/cm^3 and after 1,450 °C also 3.02 g/cm^3, whereas the raw sample had a density of 3.66 g/cm^3. This raw material, after calcining, can be regarded as a high-grade component for special technical ceramics, particularly for high-alumina refractories.

Very interesting results were obtained with the two samples from Ky Mine, marked as "Kyanite + corundum + vermiculite" (57 and 58). After separation, the resulting heavier part (about 40%) contained about 87% Al_2O_3, only 6% SiO_2 and negligible amounts of other contaminants. This part is suitable for the manufacture of high-quality mullite-corundum refractory ceramics.

Bauxite

Two samples of bauxite were delivered for testing: one from the existing Penhalonga Mine (sample 2) and another from the Bulawayo region (sample 3). The Penhalonga bauxite contained 55.5% of Al_2O_3 and showed a very high LOI (22.5%). The XRD diagramme showed only traces of quartz and muscovite and a large amount of X-ray amorphous substance. It contained also 10.3% Fe_2O_3.

The sample from the Bulawayo region contained 41.0% Al_2O_3, 44.9% SiO_2 and had a much lower LOI (12.9%). XRD indicated that the main crystalline component was kaolinite with a very distorted lattice, which could be attributed to metahalloysite. Other components appeared only in very small amounts, e.g. Fe_2O_3 about 1.3% and quartz in traces.

The Penhalonga bauxite might be further processed into pure alumina or used in the manufacture of high-alumina refractory cement. The composition of the sample of bauxite from the Beitbridge region suggests that this material might be suitable for direct use in the manufacture of aluminosilicate refractories because of its high alumina content and low content of Fe_2O_3 and alkalis. It may also find an application in the manufacture of ceramics.

Aluminosilicates

Kaolin

Seven samples of kaolin were tested: Chakari (sample 19) and its commercial form, Zimbabwe Thomson kaolin, from G & W (111), Carn Brae (75) and Carn Brae felsic kaolin (76), primary kaolin from Chiredzi (103), from Penhalonga (119) and from the private company Zamudio (123).

The quality of Chakari kaolin (19) is well known, because it has been sold on the internal market and exported as Thomson kaolin (111). ChA confirmed its high content of Al_2O_3 (about 34%) whereas DTA, TGA and XRD tests indicated that the basic component is kaolinite. As the samples contained about 1.5% Fe_2O_3 and only small amounts of alkalis, this type of kaolin has been suitable for many technical ceramics and refractories.

Three samples, Carn Brae kaolin (75), felsic kaolin (76) and primary kaolin (103) from Chiredzi did not contain kaolinite traceable by XRD. The first two contained mainly quartz, feldspar and illite, whereas the third contained pyroxenes, feldspar and traces of quartz.

Another three samples appeared to contain mainly kaolinite. These were: kaolinitic clay from Cernol Chemicals (112), kaolin from Penhalonga (119) and "talcy" kaolin from Zamudio (123). The latter contained also some amount of talc. All three samples are interasting as possible raw materials for ceramics and refractories.

Fire-clays and ball clays

Seven samples of fire-clays and ball clays were tested from four deposits. There were four samples of fire-clays from the Hwange region: one sample from the mine (109) and three from geological drilling (12-14). All four samples contained well crystallized kaolinite as a main component, in various proportions. They also contained quartz, and a small amount of illite. The highest content of Al_2O_3 was found in the sample from the mine and in one from the geological drilling - 33.7%. All samples contained a small amount of Fe_2O_3 (about 1%), about 0.5% CaO and 0.1% MgO, but about 2.5% Na_2O, and only traces of K_2O. The fire-clay from the Hwange region should be regarded as a good material for the manufacture of fire-clay refractories.

Flint clay from Chiredzi (sample 28) can be considered a very good raw material for the manufacture of aluminosilicate refractories. It contained up to 39.5% Al_2O_3 and only small amounts of contaminants: Fe_2O_3 up to 0.2%; CaO up to 0.5%; MgO up to 0.3%; Na_2O up to 0.2% and K_2O up to 0.2%. The main component, kaolinite, showed a well-ordered crystal structure. Some amount of diaspore was also present. No other minerals were found by XRD.

One sample of ball clay was delivered from the Beitbridge Mine (25). This very plastic clay is commercially available in Zimbabwe. ChA indicated an Al_2O_3

content of up to 34% and only small amounts of contaminants: about 1% of Fe_2O_3; 0.5% CaO; 0.2% MgO; 0.13% Na_2O and traces of K_2O. XRD indicated that the main component was kaolinite with distorted lattice, a small amount of illite and possible montmorillonite. Traces of quartz and feldspar were also present.

Two samples delivered by Clayproducts of Gwaai clay, "Pipe clay" and "Ladle clay" (samples 110), were quite similar in their chemical composition (up to 26-29% Al_2O_3; 3% Fe_2O_3; 0.5% CaO; 1% MgO; 1.5% Na_2O) and in mineralogical composition (kaolinite, quartz, small amounts of illite and feldspar).

Graphitic pyrophyllite

The delivered sample (29) was found to contain mainly talc and small amounts of clinochlore and graphite (only about 2%).

Bentonite

Four samples were delivered for testing: by Zamudio (5), from the Gwanda region (41), weathered basalt from Chiredzi (102) and imported bentonite from Tanzania (122). From the point of view of mineralogical composition the most interesting and promising samples were: (a) Zamudio (5), which contained as a main component dioctahedral montmorillonite of nontronite type with calcium interlayers. Peculiar for nontronite is a high content of iron oxide, in this case 5.18% Fe_2O_3. The sample contained also a small amount of fine grained quartz; (b) the sample from the Gwanda region (41), which contained as a main component a mixed layer of montmorillonite-chlorite mineral, traces of kaolinite and small amounts of quartz and feldspar. The other two samples will probably have no relevance as raw materials: the first one because its mineralogical composition is not suitable (102), and the second because it is imported (122).

Brick clays

Six samples of brick clays were tested (32, 113-117). Numerous technological tests were performed on four samples of brick clays from Mt. Hampden (near Harare) (113-116), with regard to their possible application in the manufacture of wall tiles. From the mineralogical point of view they contained small amounts of kaolinite, quartz, feldspar and illite. They contained about 18.5% Al_2O_3; 7% Fe_2O_3; 5% Na_2O + K_2O and 53% SiO_2.

Feldspars

The high quality of Zimbabwean feldspars is well known and some of the deposits have been mined for many years. For testing six samples were delivered: four from the Bikita Mine (11, 93-99), one from Borrowdale (23) and one from Mistress Mine (46). All Bikita samples contained mainly microcline and only small amounts of such unwanted components like Fe_2O_3 (0.29%) and TiO_2 (0.17%). They have pertite character. The sample from Mistress Mine (46) contained albite and only traces of Fe_2O_3 and TiO_2. The last sample from Borrowdale (23) had also microcline and pertite character and contained only traces of Fe_2O_3 and TiO_2. Thus all the samples could be regarded as very good raw materials for ceramics, glazes, glass and other applications.

Lithium-bearing minerals

Zimbabwe has a world-wide reputation as a producer of lithium minerals. This concerns the Bikita Mine, from which four samples were brought for testing (6-9): spodumene (6), which contained 5.6% Li_2O; lepidolite (7) with 1.94% of Li_2O and 5.25% of Rb_2O; amblygonite (8) containing 2.15% Li_2O and 45.1% P_2O_5; and petalite with 2.26% Li_2O. Apparent petalite from Mistress (45) did not contain Li_2O and appeared to be albite, with 10.92% of Na_2O.

Cesium-bearing minerals

An interesting sample of pollucite from the Bikita Mine (10) contained 22.44% of Cs_2O.

Vermiculite

Five samples of vermiculite were obtained for testing: from Nyazura (24), from Ky Mine (55), two from Dorowa (90 and 92), and one commercial from G & W (120). All have been tested, especially their grain size and exfoliation factor.

Magnesium and calcium carbonates

Magnesite

Two samples of magnesite were delivered for testing: from Kadoma (21) and from the Pande Mine, near Beitbridge (31). Whereas Kadoma magnesite had already been analysed by Budimir and Vlajcic (see annex II) through ChA, DTA, XRD, X-ray microprobe and technological tests, much less was known about Pande Mine magnesite (31). It was found that this magnesite, when compared with Kadoma magnesite, contained much less calcia, only about 0.5%. The main contaminant seemed to be silica of about 5%. However, selected white samples could be regarded as a very pure magnesite (LOI = 50.0%). Other pieces of the sample were apparently contaminated by talc. More tests with this interesting magnesite are necessary.

Dolomite

Numerous samples of dolomites were delivered. These were: from Rushinga (18), Gundi Park (65-67 and 72-74), Alaska Mine (68-71) and milled dolomite from G & W (121). The last one could be regarded as almost pure dolomite, with minute excess of calcite, LOI = 45.4%. All other dolomites appeared to be of calcitic character (with excess of $CaCO_3$). Generally they contained only a small amount of Fe_2O_3 (less than 1.0%, and for Alaska even less than 0.2%). The best, with the highest LOI and the lowest SiO_2-content appeared to be Alaska dolomite III (70) LOI = 44% and Gundi Park V (73) LOI = 45% and SiO_2 = 44%. After dead burning, they might be suitable for linings of blast-oxygen furnaces.

Limestone and calcite

Altogether 11 samples were delivered: calcite from Routen Back (17), limestone from Early Worm (20), crystalline limestone from Bombodza (47-49), coarsely crystalline calcite from Rogo (52-54), limestone from Houghton (96 and 97), and limestone from Falcon Limes (100). Six of them appeared to be calcitic dolomites, with various proportions of $CaCO_3$ and $MgCO_3$ (samples 17, 52-54, 96 and 97). Samples 17 and 52-54 contained only small amounts of Fe_2O_3

and Al_2O_3 (about 0.5%). The purest samples, containing only calcite, were those from Falcon (100), Bombodza (48) and Early Worm (20).

Magnesium silicates

From among seven samples of talc only three appeared to be pure talc, at least to some extent: two from Wadzanai (87 and 88) and one from Cernol Chemicals (118). All others - from Kwekwe (22), impure talc from Filabusi (30), talc/kaolin from Concession (78) and a sample from G & W (125) - contained considerable amounts of magnesite, and in one case (78) also clinochlore. Three samples from Great Dyke: serpentine/verdite (105), dunite (107), and serpentinized dunite (108) contained 52-58% SiO_2 and 30-32% MgO. Dunite (107) contained considerable amounts of Al_2O_3 (7.4%) whereas serpentinized dunite had more than 8% of Fe_2O_3. Serpentine/verdite (105) seemed to be very pure, containing only 3.15% Fe_2O_3, with a LOI of 7.10%. The proportion of MgO : SiO_2 was 0.52. The highest proprotion of MgO : SiO_2 = 0.66 was found in serpentinized dunite (108), unfortunately with a high content of Fe_2O_3 (8.2%). It is doubtful if these rocks could be regarded as raw materials for the manufacture of forsterite refractories.

Silica

Quartzite

Eleven samples were delivered for testing, but two of them have not yet been tested (101 and 102). The most contaminated sample was "rough quartz" from Mistress (44). It contained only 75.36% SiO_2 and showed a very high LOI of 11%. It is possible that the average sample taken for ChA was particularly contaminated with clay. To obtain quartzite of better quality, it would be advisable to wash it with water.

The highest content of SiO_2 was found in rough quartzites from the TOT deposit (50 and 51) and from Slam 3 (80 and 81) - up to 93.8%, as well as from Ulva Farm (84-86) - between 88.4% and 93.0%. The quartzite from Mushandike Ranch (Sebakwe) (98) also had a high content of SiO_2 - 89.8%. However, all tested samples were contaminated either with clay minerals (samples 85, 86 and 98) or with feldspars (samples 50, 51, 80, 81 and 84). The content of Fe_2O_3 was found to be very low (0.1-0.3%) in samples 44, 80, 81, 84-86 and 98. It can be concluded that most of the above-mentioned quartzites are suitable as raw materials for the ceramic and refractories industries.

Diatomaceous earth

A sample of diatomaceous earth (33) from Chemutsi Deposit, Chirundu, had been tested in 1985 by R. D. Morton (see annex II). DTA, TGA and XRD analysis performed under the project indicated the presence of traces of quartz and feldspar. LOI was comparatively low, only 7.3%. To establish the value of this material, further technological tests are necessary.

Other samples

Apatite

Two samples (89 and 91) were delivered from Dorowa Minerals. ChA indicated that they have a similar composition. The deposit at Dorowa is mined and apatite beneficiated on an industrial scale. The upgraded material is being sent to Zimphos for the manufacture of phosphoric acid and mineral fertilizers.

Baryte

Four samples were delivered for testing: one from Guruve (15), two samples from Dodge (82 and 83) and one from Argosy (99). The latter (99) contained only 1.87% BaO and 92.52% SiO_2. The measured density was only 2.9 g/cm^3. It was obvious that it could not be regarded as a baryte. The sample from Guruve (15) contained 88.06% $BaSO_4$; 6.16% SiO_2 and only 0.57% Fe_2O_3. After beneficiating this baryte can be regarded as a proper raw material for further processing (mechanical for heavy drilling muds and chemical for other purposes). Two samples are still being tested (82 and 83).

Fluorite

Two samples were tested: One from Macoosa-Chiredzi (27) and one from the Beitbridge region (40). The first one (27) contained 90.26% CaF_2, only 0.08% SiO_2 and 0.43% Fe_2O_3 as well as 0.24% PbO. It could be regarded as a No. 2 ceramic grade and metallurgical grade material. The second sample (40) could be hardly regarded as a fluorite, as it contained only 1.68% CaO and 4.80% F, but 52.50% SiO_2, 32.0% Al_2O_3 and 10.28% MgO.

Graphite

Two samples from Lynx Mine (60 and 61) are still being tested.

Nepheline-syenite

One sample (106) from the Marangudzi Complex near Beitbridge was analysed by ChA. It was found to contain 7.41% Na_2O, 6.50% K_2O, 2.66% CaO, 0.58% MgO, as well as 59.16% SiO_2 and 18.10% Al_2O_3, but a considerable amount of Fe_2O_3 - 4.58%. It might be used as a raw material in such cases (glass, glazes) where a high Fe_2O_3 content can be tolerated.

Perlite

One sample (42) from the Beitbridge region is being tested.

Fly ash

Fly ash from Hwange Power Station (16) was tested and found to contain 28% Al_2O_3 but also 5.15% Fe_2O_3, 6.44% CaO, 2% Na_2O and 6.35% P_2O_5, with a LOI of 9.1%. The conclusion is that it cannot be used for refractories manufacture, but should be tried as a component for wall tiles, floor tiles, building bricks and Portland cement.

General conclusions on tested samples

Although the testing of samples is still in progress, one can conclude from the results obtained up to now that the country possesses various alumina-bearing raw materials which, in the future, may constitute a basis for the development of new technologies such as the production of high-alumina super-duty and high-duty refractories, technical ceramics, special ceramics, refractory cements and concretes, mineral wool and fibres, mineral binders etc.

Numerous samples of aluminosilicates indicate that it will be possible to substitute all imported raw materials for the manufacture ceramic bodies and glazes used in the tableware and sanitary-ware industries, as well as for the manufacture of wall tiles.

Very interesting and promising are magnesites, both from Kadoma and especially from Beitbridge which have not yet been sufficiently evaluated. Most probably they can lay the basis for the development of a Zimbabwean industry of basic refractories, considering that the other component of such refractories, chromite, is abundant in this country.

The tests of numerous samples of carbonates indicate that there are good dolomites, in which the metallurgical industry might be interested. Of even higher importance are limestones with a high content of calcite. Some of them contain only traces of Fe_2O_3 and might be interesting for the glass and the ferro-chrome industries.

B. Equipment and methods of testing

The equipment delivered under the project permits to carry out various tests on non-metallic raw materials and products. Particularly important are methods of mineralogical analysis like XRD, DTA, TGA and TDA, which are complementary to ChA performed in the Chemical Laboratory of DOM. It should be stressed, however, that ChA is done mainly by the "wet method". The existing equipment of the Chemical Laboratory, which permits a fast and precise so-called instrumental analysis based on physical principles, does not comply with the standards of a modern analytical laboratory.

In terms of staff, methods and equipment, the Ceramic Laboratory at DOM is now able to perform a series of basic tests on non-metallic raw materials and products and to adapt others for which the existing equipment can be used. However, refractories and their raw materials cannot be properly tested due to a lack of the necessary equipment. Also, pilot-scale tests of ceramic and refractories technologies are practically impossible, because the necessary space and equipment, especially high-temperature furnaces are not available. Other technical facilities, such as all kinds of workshops, are also insufficient.

C. Technical and scientific information

Although there is no proper library at DOM, it is possible to obtain some of the necessary technical and scientific information from the libraries at GS, IMR, SACA and the Main Library at the University of Zimbabwe. The periodicals and books obtained under the project can be regarded as a first step towards the establishment of a technical information centre on non-metallics at DOM.

D. Co-operation with the industry

This co-operation started almost at the beginning of the project, and a variety of problems were submitted to the Ceramic Laboratory, such as: evaluation of samples of potential raw materials; advice on the substitution of imported raw materials by domestic ones; advice on the proper use of refractories; advice on the technology of refractories (see annex VI); testing of ceramic products; requesting DOM to manufacture some special refractory products etc. The interest of the industry to co-operate with DOM in the field of non-metallics has been permanently growing.

Annex I

JOB DESCRIPTION

Post title: Expert in testing, classifying and evaluating non-metallic raw materials

Duration: Twelve months

Date required: April 1985 (subject to the delivery of equipment in the field)

Duty station: Harare, with travel within the country

Purpose of project: To provide technical assistance to the laboratories of the Department of Metallurgy in testing, classifying and evaluating non-metallic raw materials, in putting new equipment into operation and training local technicians to operate it

Duties: The expert will be attached to the laboratories of the Department of Metallurgy and will specifically be expected to:

(a) Study all reports available on local non-metallic raw materials;

(b) Select those deposits of non-metallic raw materials with the most potential;

(c) Assist the laboratory in selecting, erecting and operating additional equipment needed for testing and researching into non-metallic raw materials;

(d) Introduce to the laboratories standard methods for testing non-metallic raw materials;

(e) Conduct laboratory tests on selected non-metallic raw materials;

(f) Train counterpart personnel to test, classify and evaluate non-metallic raw materials;

(g) Identify training needs and recommend training programmes for local engineers to test, classify and evaluate non-metallic raw materials.

The expert will also be required to prepare a final report, setting out the findings of the mission and recommendations to the Government on further action which might be taken.

Qualifications: Silicate engineer, or equivalent, with experience in testing, classifying and evaluating non-metallic raw materials

Language: English

Annex II

REPORTS ON LOCAL NON-METALLIC RAW MATERIALS

ANDERSON, R. B. A handbook of useful information regarding base minerals. Mines department bulletin 6, 1962.*

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MORRISON, E. R. Corundum in Rhodesia. Geological survey - mineral resources series No. 16, 1972.*

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MORTON, R. D. Report on diatomaceous earth production and chemutsi diatomaceous earth property for Z.M.D.C. Harare, 15 February 1985.**

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VLAJCIC, J. and I. BUDIMIR. Strengthening government support services in non-metallic mineral sector. Investigations on the possibility of beneficiating of local raw magnesite for the production of basic refractories. 1985. (DP/ZIM/83/006)*

WARNER, S. M. Check list of the minerals in Rhodesia. Geological survey bulletin 69, 1972.*

ZIKA, Z. Preliminary assessment of the techno-economical conditions of the possibilities of processing aluminosilicate/kaolin concentrate with the view to obtain highly competitive end products, for example, electrical insulators, aluminium-silicon alloy etc., 1983. (SI/ZIM/82/801/11-03)*

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*Documents available at Department of Metallurgy of the Ministry of Mines, Harare.

**Documents available at Department of Metallurgy of the Ministry of Mines, Harare and Zimbabwe Mining Development Corporation, Harare.

Annex III

MINERALS AND ROCKS TO BE INCLUDED IN THE "GEOLOGICAL INVENTORY OF ZIMBABWE"

A. Raw materials for the ceramic industry

The following raw materials may be used for the production of fine ceramics, sanitary ceramics, technical ceramics, refractories, special ceramics, glass and building ceramics.

1. Alumina-bearing minerals and rocks

1.1. Corundum (Al_2O_3) - For the refractories industry (corundum and high-alumina refractories, melt-casted refractories), for abrasives and special ceramics.

1.2. Diaspore, gibbsite ($AlO(OH)$, $Al(OH)_3$) - For the refractories industry (corundum and high-alumina refractories, refractory alumina cements), for special ceramics and in the chemical industry as well as for aluminium metallurgy.

1.3. Bauxites - For refractories (high-alumina refractories), refractory cements, chemical industry. Also poor alumina bauxites should be taken into account for industry, aluminium metallurgy.

1.4. Kyanite, sillimanite, andalusite (Al_2SiO_5) - For high-duty aluminosilicate refractories, mullite manufacture by sintering or melting, for special technical ceramics, electroporcelain, mineral fibres (type "Fibrefrax"), aluminium metallurgy.

1.5. Koalins - For many branches of the ceramic industry and especially for fine-ceramics, some technical ceramics, refractories, as well as for many other applications (e.g. as filler in the paper industry, cosmetics etc.).

1.6. Halloysite - Application like kaolins (to a limited extent).

1.7. Clays (or fire-clays) - General rule: the higher the Al_2O_3 content of a clay and the lower the content of Fe_2O_3, FeO, CaO, K_2O and Na_2O, the better the quality of a clay.

The main component of such clays should be kaolinite. They may have either plastic character - so-called "ball clays" (e.g. Beitbridge clay) or non-plastic character ("rock" appearance) - so-called "flint clays" (e.g. Chiredzi and Chivumburu flint clays).

These types of clays are basic raw materials for aluminosilicate refractories, for fine-ceramics, sanitary ceramics or technical ceramics.

1.8. Brick clays - They are perhaps of lesser importance to the project, however, they are wide-spread in the country and used for the manufacture of building ceramics, bricks, roof tiles, floor tiles, wall tiles etc.

1.9. Illites - Used as a component in fine-ceramics.

2. Other aluminosilicate raw materials

2.1. Feldspars: potassium, sodium, calcium and some lithium aluminosilicates (albite, orthoclase, microcline, anorthite and petalite, spodumene, lepidolite, eucriptite) - For the glass industry and the manufacture of ceramic bodies, glazes and frits.

2.2. Nepheline syenite - For the glass industry, as well as for glazes and frits.

2.3. Feldspar sands - Application as feldspars.

2.4. Talc - For electrical ceramics (steatite - dielectrics), cordierite ceramics, refractory ceramics and for other purposes, e.g. cosmetics.

2.5. Cordierites - For special cordierite ceramics with a low thermal expansion coefficient and cordierite refractories with high thermal shock resistance.

2.6. Vermiculite - For thermal and acoustic insulation (after exfoliation).

2.7. Bentonites (montmorillonites) - For special purposes in the ceramic industry, in foundries, in geological drilling, in the food industry etc.

2.8. Zeolites - Although they have no major application in ceramics they are used in various other branches where their ion-exchanging and adsorbing properties are useful.

2.9. Industrial garnets - For abrasives.

3. Silica-bearing minerals and rocks

3.1. Quartz (mono-crystals) - For electronics and for silica glass manufacture.

3.2. Quartzites - For silica refractories (lining of coke ovens, furnaces for melting glass etc.) for the metallurgical industry (among others for ferro-alloys).

3.3. Quartz sands - With a low content of Fe_2O_3 for the glass and ceramic industries. Other quartz sands are used in building ceramics, and the manufacture of lime-sand (or silicate) bricks, for foundry moulds and for the manufacture of technical ceramics, e.g. silicon carbide.

3.4. Diatomaceous earth - For thermal and acoustic insulations, in the chemical and food industries as an adsorbant etc.

3.5. Tridymite - For silica refractories.

4. Silicates

4.1. Wollastonite ($CaSiO_3$) - Used as a component of various ceramic bodies, among others for low-loss electro-ceramics and for ceramic glazes.

4.2. Dunite - For basic refractories of forsterite type.

4.3. Forsterite (Mg_2SiO_4) - For basic refractories.

4.4. <u>Zircon</u> ($ZrSiO_4$) - Very valuable raw material for highly refractory ceramics, special technical ceramics, and as a component of ceramic glazes.

4.5. <u>Phenacite</u> (Be_2SiO_4) - For highly refractory and thermal shock-resistant special ceramics, as well as special ceramics for nuclear reactors.

5. <u>Carbonates, oxides, and hydroxides of magnesium and calcium</u>

5.1. <u>Periclase</u> (MgO) <u>and brucite</u> ($Mg(OH)_2$) - For basic refractories (periclase type or periclase-spinelide type), as well as for other purposes (e.g. pharmaceutical and chemical industries).

5.2. <u>Magnesite</u> - Mainly for basic refractories (periclase-type magnesite refractories or periclase-spinelide type chrome-magnesite and magnesite-chrome refractories) as well as to some extent in the building industry.

5.3. <u>Dolomite</u> - For basic refractories (lining of oxygen convertors and rotary cement kilns etc.), as well as for other applications.

5.4. <u>Calcite, limestone and chalks</u> - For a wide range of applications: ceramic and refractories industries, metallurgical industry, building industry, cement industry, glass industry, food industry (e.g. sugar industry), chemical industry (for various purposes, e.g. manufacture of soda, calcium carbide etc.).

B. <u>Minerals and rocks for other applications</u>

1. <u>Sulphates</u>

1.1. <u>Barites</u> ($BaSO_4$) - Mainly for the chemical industry (white pigments) as well as for the glass industry and for the manufacture of barium-aluminate cements and celsian-type ceramics.

1.2. <u>Celestine</u> ($SiSO_4$) - For the chemical industry.

1.3. <u>Gypsum</u> ($CaSO_4.2H_2O$) <u>and anhydrite</u> ($CaSO_4$) - For the Portland cement industry, the building industry, as a building agent in constructions, for the manufacture of internal walls in buildings, of plaster moulds in ceramics etc. However, it should be taken into account, that gypsum is being manufactured in large quantities as a by-product (or just a waste) by the phosphate fertilizers industry (Zimphos).

2. <u>Phosphates</u>

2.1. <u>Apatite</u> - For the fertilizer and chemical industries (manufacture of phosphoric acid, which is also applied in ceramics).

2.2. <u>Monazite</u> ($(Ce, La)PO_4$) - A source of CeO_2 and La_2O_3, which play a particular role in some kinds of special technical ceramics.

2.3. <u>Xenotine</u> (YPO_4) - A source of Y_2O_3, which plays some role in special ceramics (e.g. the component of translucent alumina tubes for sodium lamps).

3. Other minerals

3.1. Graphite - An important component of so-called "graphite refractories", among others used for the manufacture of refractory graphite crucibles. Various other important industrial applications.

3.2. Fluorite of fluorspar (CaF_2) - Various applications mainly in metallurgy and chemistry, but also in the glass cement and ceramic industries.

3.3. Sulphur (native) - For the chemical industry.

C. Comments on other minerals and rocks

The expert has not included various so-called "metallic minerals", which, however, do have a wide application in the ceramic industry, e.g. chromites in manufacturing basic refractories of the chrome-magnesite type; various oxides like MnO_2, CaO, SnO_2 for ceramic pigments and colours; or cassiterite (SnO_2) for special semi-conducting ceramics; or ThO_2 for highly refractory ceramics.

In preparing the inventory, priority should be given to alumina-bearing and aluminosilicate raw materials, because the problem of supplying existing ceramic factories in the country (including one factory manufacturing normal-duty aluminosilicate refractories) with suitable domestic raw materials may arise.

Other non-metallic raw materials should also be investigated, such as pegmatites, volcanic glasses and ashes, and perlite.

Asbestos has not been included, because its mining and processing industry is very well developed in Zimbabwe.

Annex IV

POSSIBLE RESERVES OF NON-METALLIC MINERALS IN ZIMBABWE

	Million tonnes
Apatite	30
Amblygonite	0.1
Barytes	2
Bauxite	3
Brick-clay	1,000
Calcite	0.5
Celestine	0.001
Corundum	10
Diatomaceous earth	0.1
Dolomite	1,000
Dunite	100
Epidote	1
Feldspar	1,000
Fire-clay	1
Flint clays	50
Fluorspar	0.01
Garnet	50
Graphite	10
Gypsum	No natural occurrence (by-product of Zimphos)
Kaolin	100
Kyanite	100
Limestone	1,000
Lepidolite	0.2
Magnesite	10
Mica	20
Montmorillonite	0.01
Nepheline syenite	1,000
Perlite	5
Quartz	1,000
Quartzite	1,000
Serpentine	1,000
Silica sand	1,000
Talc	1,000
Vermiculite	100
Zeolites	0.001
Zircon	100

Annex V

LECTURES AND SEMINARS GIVEN BY THE EXPERT AT THE DEPARTMENT OF METALLURGY

Ceramics as a construction material.

Thermal methods of testing non-metallic raw materials: DTA, TGA, TDA.

Rheology of non-Newtonian liquids, as applied in testing ceramic slips and masses: viscosity.

Newtonian fluids. Laminar and turbulent flow.

Non-Newtonian fluids: pseudoplastic, dilatant, plastic. Time factor: thixotropy and rheopexy. Bingham flow.

XRD-phase analysis: identification and determination of crystalline phases. Mineralogical analysis.

Clays - their mineralogy, structure, properties and testing.

Unit operations and processes in ceramic technology:

(a) Crushing and milling;

(b) Preparation of masses;

(c) Forming;

(d) Drying;

(e) Firing.

Some products based on non-metallic raw materials - the technology of their manufacture and application:

(a) Refractories, their systematics and methods of testing;

(b) Silica refractories - raw materials and their properties. The manufacture and application of silica refractories;

(c) Aluminosilicate refractories - semi-acid, fire-clay, sillimanite (kyanite), mullite, mullite-corundum, corundum. Raw materials and their testing. The technology of their manufacture and application.

Annex VI

THE PRODUCTION OF REFRACTORIES IN ZIMBABWE

A. The present situation

Raw materials

The country is rich in a variety of good refractory raw materials. This goes particularly for excellent raw materials for high-quality alumina and aluminosilicate refractories such as corundum (for high-alumina refractories and masses) kyanite (for sillimanite-type high-duty refractories), fire-clays of flint and ball type (for high-duty fire-bricks and masses), as well as kaolins. The estimated deposits of some of them amount to hundreds of million tonnes, and many of them are being mined.

Other refractory raw materials found in Zimbabwe are magnesite and chromite. Magnesite from Kadoma, however, which is of dolomitic character and contains a high percentage of calcia, cannot be used without treatment for the manufacture of high-grade refractories. Further interesting raw materials are: quartzites for the manufacture of silica refractories; graphite for refractories of Plumbago-type and crucibles; and another highly refractory raw material such as zirconium orthosilicate (zircon), about which the expert could not obtain sufficiently detailed information.

Manufacturers of refractories

Two factories in Zimbabwe are manufacturing refractories. Clay products at Bulawayo uses for the production of fire-bricks and shapes of normal-duty grade, mainly for Zisco, only local raw materials (fire-clay). They also manufacture ramming masses and castables, the main component of which is grog, made of local raw materials. The binding agent, alumina or high-alumina refractory cement, is, however, imported.

The other, much smaller factory, is Redcliff Castables, which manufactures mainly castables and ramming masses on a similar principle as Clay Products, but uses as a filler for castables and masses recycled and crushed refractories (high-alumina and magnesite bricks) from Zisco. The refractory cement is also imported. Redcliff also manufactures phosphate-bound aluminosilicate crucibles.

At the Department of Metallurgy some ceramic aluminosilicate crucibles were manufactured for some time, however, most of the refractories used in Zimbabwe are being imported.

Testing and evaluation of raw materials

The methods for the determination of the chemical and mineralogical composition of raw materials adopted at the Department of Metallurgy are mainly chemical analysis, DTA, TGA and TDA. Although thermal methods are useful, the most versatile and precise method, XRD, should be applied.

Furthermore, the thermal expansion coefficient can be determined. The high-temperature laboratory furnace permits the determination of the sinterability of refractories, their porosity and density after firing, and their secondary volume change. It was also found possible to estimate the refractoriness and slag-resistance of refractories by the pellet method, again by using the high-temperature furnace.

Current involvement of the Department of Metallurgy in the problem of refractories' production

Since refractories are an essential structural part of all equipment working at high temperatures, particularly of various kilns, furnaces, crucibles, moulds etc. in metallurgy, the Department of Metallurgy should be, and is, actively involved in overcoming problems concerning the local production of refractories.

Kadoma magnesite has previously been tested under the project. With the introduction of new testing methods for refractories at the Department of Metallurgy, co-operation has started with ZMDC on the evaluation of various raw materials, among others to establish their suitability for the manufacture of refractories.

In addition, the Department of Metallurgy has started to manufacture graphite crucibles. First positive results have been obtained.

B. Recommendations for the development of a refractories production

The role of the Department of Metallurgy

The Department of Metallurgy should concentrate on research on raw materials for refractories (quality and suitability), on some technologies of refractories' manufacture, on the technology of their application in various industries, as well as on a small-scale production of special wares. The reasons for this proposal are:

(a) There is staff, who has been prepared to perform these tasks in the future, although further training under UNIDO fellowships, to gain the necessary experience will be necessary;

(b) The Department is now quite well equipped and some additional items (e.g. XRD) are expected to arrive soon. The laboratory will thus be able to perform all necessary tests (especially mineralogical analysis) of various raw materials.

The question of equipment for the future pilot plant is still open. In the expert's opinion, it should be equipped, first of all, for research in refractories, because, so far, only a small quantity of one kind of normal-duty fire-clay refractory material is being manufactured in Zimbabwe, while local deposits of raw materials are immense and of a very good quality.

In this context, the expert would like to recall one of his recommendations in his first quarterly report, namely that the pilot plant, regardless of what kind of ceramics will be developed, should be provided with a big chamber furnace for temperatures up to 1,600 °C. For testing refractory raw materials a proper laboratory furnace for PCE measurements is indispensable. The pilot plant should also be provided with a universal hydraulic press, both for dry-pressing and measurement of compression strength of refractories and other structural ceramics.

The Department of Metallurgy should concentrate on solving the following problems in the near future:

(a) To continue working on the manufacture of graphite crucibles, considering the application of a phosphate binder. The staff of the Department who have gained some experience in that kind of manufacture, should be able to solve this problem very soon;

(b) To investigate the possibility of direct application of boulder corundum from Concession Mine, in the form of blocks or grog, as a refractory construction material;

(c) To develop other types of ramming masses, by using calcined kyanite, boulder corundum or silica as a grog;

(d) To develop new types of aluminosilicate ramming masses with phosphate bond;

(e) To continue developing the production of small laboratory ceramics (small crucibles, lids, supports, shapes), by plastic and semiplastic forming, and firing at temperatures up to 1,300 °C in the electric furnace (with Kanthal Al heating elements);

(f) To research into the technology of application of refractories, to advise users on their proper applications and prepare an inventory of users of refractories in Zimbabwe.

Development of the production of aluminosilicate refractories at Clay Products, Bulawayo

During his visit to Clay Products in August 1985, the expert pointed out to their manager that with such good raw materials on the one hand, and some experience in the manufacture of refractories on the other hand, it should be easy for them to develop their production of aluminosilicate refractories both in quantitative and qualitative terms, by producing high-duty, super-duty and high-alumina refractories. For that purpose the plant would have to be modernized, especially in the pressing and firing operations.

For firing, the expert suggested to construct a new efficient tunnel kiln for temperatures up to 1,500 °C or even higher.

The expert proposed that a skilled design engineer, with experience in the aluminosilicate refractories industry be invited, for not more than one month, to study the existing situation and possibilities and to advise the company on which new equipment should be installed. His report should be the basis for all future action.