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LOCAL DEVELOPMENT OF AFFORDABLE LIME IN SOUTHERN AFRICA

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with contributions from
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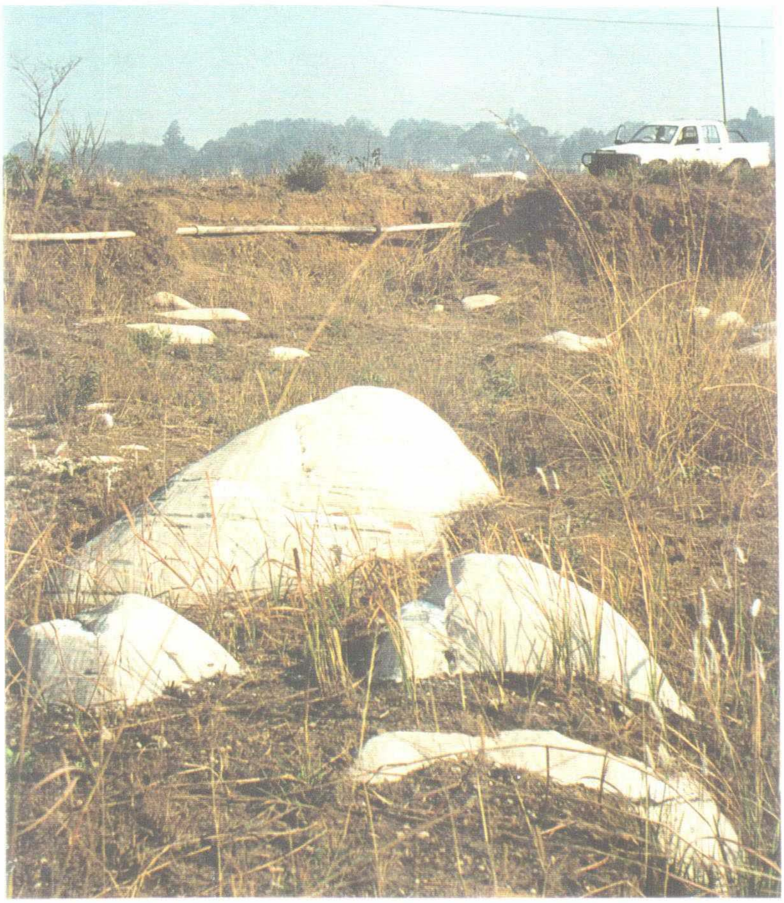

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EXECUTIVE SUMMARY

Lime is an important and versatile chemical used in a wide range of applications. The term lime, which is strictly calcium oxide (CaO), is applied to a range of products arising from the processing of limestone and dolomite. Many less developed countries do not have adequate lime production and this leads to problems associated with under-utilisation of lime. In particular, insufficient application of agricultural lime (aglime) can lead to soil acidification, with associated aluminium / manganese toxicity and poor crop yields.

As part of the UK Government's commitment to provide technical assistance to developing countries, a project was initiated to help solve this problem. The BGS / Department for International Development (DFID) project "Local development of affordable lime in Southern Africa" (R6492) aimed to encourage the development of low-cost lime for agriculture and water treatment. As part of the project, carbonate resources were matched with appropriate lime production technology to provide a methodology for the establishment of local production units. This document is a compilation of reports, including the project deliverables. It is a companion document to the project summary report (WC/98/21).

The project was undertaken in collaboration with the Zambian Geological Survey Department (GSD)and Intermediate Technology Zimbabwe (ITZ). It focused on aglime production in Zambia, following the recommendations of a recent survey of the lime industry of the Southern African Development Community (SADC) region (AUSTROPLAN, 1990). The project was divided into three main activities:

1) Lime evaluation programme
2) Small-scale lime production research
3) Dissemination

The aim of the lime evaluation programme was to identify carbonate resources suitable for use as lime close to the point of need. A 'market survey' was carried out to determine the demand for lime, its quality, quantity and where it is most needed. The findings indicated that Zambia has a suppressed demand for aglime, especially in the northern provinces and those provinces more heavily cultivated. Aglime consumption is held back by its poor availability and relatively high cost.

A review of the carbonate resources of Zambia identified numerous dolomitic carbonates that are potentially suitable for the production of aglime. Most of the carbonates occur in the Basement Complex and the Katanga Supergroup, along the line of rail from Livingstone up to the Copperbelt and North-Western provinces, as well as smaller deposits in Luapula, Northern and Eastern provinces.

Appropriate laboratory evaluation test methods were identified to determine the properties that are critical for the effective use of limestone and dolomite as aglime, as follows:

i) Plant nutrient content, especially calcium and magnesium oxide content
ii) Neutralising ability, important for amelioration of soil acidity
iii) Particle-size distribution, a principal factor in controlling the effectiveness of aglime
iv) Agronomic effectiveness, the rate at which aglime reacts to neutralise soil acidity
v) Ease of pulverisation (or grindability), an important factor in the production of ground limestone and dolomite

A carbonate-sampling programme resulted in the collection of 35 samples from approximately 20 sites across Zambia. All the samples were evaluated, firstly for their mineralogy and major element chemistry at the BGS, and secondly for their plant nutrient content, neutralising ability, agronomic effectiveness and ease of pulverisation at the GSD. The test results were used to "screen" the samples, those with Neutralisation Values higher than 80% calcium carbonate equivalent (CCE) and more than 6% magnesium oxide were considered to be suitable for use as aglime.

The aim of the small-scale lime production research was to identify a low-cost method for the small-scale production of lime. A review of small-scale lime production practices in Zimbabwe was carried out by ITZ. The most appropriate small-scale method for the production of aglime would probably involve contract extraction, manual crushing and dressing, mechanical milling and manual bagging. The cost of producing aglime using a small-scale method would be approximately US$29 per tonne (1997 prices). Also, the Technology Development and Advisory Unit (TDAU) at the University of Zambia (UNZA) carried out a small-scale lime production trial. A bulk sample of dolomitic carbonate from Mkushi was milled using the TD hammer mill and the resulting product was sufficiently fine grained enough to be used as aglime.

As part of the dissemination process, a workshop was held at the Pamodzi Hotel, Lusaka in February 1998. At this meeting representatives of Government Ministries and research institutes, as well as UNZA and the farming community, met to learn of the project findings and also to discuss the 'way forward' for small-scale lime production and use.

Recommendations for the evaluation and production of lime are summarised below:

i) A survey of the lime market and a review of the carbonate resources is recommended in order to identify appropriate local production sites.
ii) Identification of suitable laboratory test procedures and a lime evaluation programme is recommended in order to identify those limestone and dolomite samples that are suitable for use as lime.
iii) Identification and testing of production methods is recommended in order to develop the most appropriate procedure for the small-scale production of lime.

INTRODUCTION

Lime is an important and versatile chemical that is widely used in a range of industrial and other applications. In particular, lime is used to condition soil and treat drinking water. Many less developed countries do not have adequate lime production, leading to under-utilisation of lime and problems such as soil acidification and poor crop yields.

As part of the UK Government's commitment to provide technical assistance to developing countries, a project,“ Local development of affordable lime in Southern Africa" (R6492), was initiated to encourage the development of low-cost lime for agriculture and water treatment. The project was funded by the Department for International Development (DFID) under its Knowledge and Research (KAR, formerly the Technology Development and Research) programme. The work was carried out by the British Geological Survey (BGS) in collaboration with the Zambian Geological Survey Department (GSD) and Intermediate Technology Zimbabwe (ITZ).

The objective of the project was to provide a methodology for the small-scale production of lime close to the point of need. Following the recommendations of a recent survey (AUSTROPLAN, 1990) of the lime industry of the Southern African Development Community (SADC) the project focused upon agricultural lime (aglime) production in Zambia. The project was divided into the following three main activities:

1) LIME EVALUATION PROGRAMME

The aim of this activity was to identify carbonate resources close to the point of need and evaluate their potential for use as aglime. This involved the following:

Section A: Market survey of agricultural lime use in Zambia

A 'market survey' was carried out to determine the state of the lime market. This involved reviewing existing data and information, and a questionnaire 'mailshot'. The findings are presented, along with a discussion of the means to stimulate lime production.

Section B: Review of the carbonate resources of Zambia

A review of limestone and dolomite resources was carried out to identify occurrences potentially suitable for use as aglime. This involved reviewing the geological maps and reports of the GSD and the Mineral Exploration Department, along with other sources.

Section C: Laboratory analysis of limestone and dolomite for use as agricultural lime

Appropriate laboratory test methods were identified to aid evaluation of limestone and dolomite for use as aglime. This involved reviewing the technical and scientific literature and laboratory trials at the BGS to validate the methods identified. Step-by-step procedures for each of the laboratory methods recommended are given in the appendices.

Section D: Lime evaluation programme: Findings & results

An evaluation programme was carried out to identify limestone and dolomite suitable for use as aglime. This involved the collection of limestone and dolomite samples from across Zambia and their evaluation in a dedicated laboratory at the GSD. The results are presented, along with a list of those carbonates identified as suitable for use as aglime.

2) SMALL-SCALE LIME PRODUCTION RESEARCH

The aim of the lime production research was to identify a low-cost method for the small-scale production of lime. This involved the following:

Section E: Review of small-scale lime production in Zimbabwe

A review of small-scale lime production practice was carried out by Intermediate Technology Zimbabwe (ITZ). This involved visiting lime production operations throughout Zimbabwe, as well as an analysis of the economics of each production stage.

Section F: The milling of agricultural lime

A production trial was carried out by the Technology Development & Advisory Unit in Lusaka to determine the effectiveness of a mill for the small-scale production of aglime. This involved the milling of dolomitic marble from Mkushi using the TD hammer mill. The results are presented, along with an analysis of the economics of operation.

3) DISSEMINATION

The aim of the dissemination process was to enable industrial and agricultural concerns to learn of, and act on, the findings and results of the project.

Section G: Local development of affordable lime in Southern Africa Workshop

A workshop was held in Lusaka in February 1998 to discuss the project findings. The workshop abstracts, as well as a summary of the issues raised during a 'brainstorming' session on the 'way forward' for lime production and consumption, are presented.

Section H: Recommendations for the evaluation and production of lime

The recommendations for the evaluation and production of small-scale lime are presented.

SECTION A:
MARKET SURVEY OF AGRICULTURAL LIME USE IN ZAMBIA

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1. INTRODUCTION

Lime is an important commodity, chiefly used in industry as a source of calcium, as a metallurgical flux, as a means of controlling pH, in waste and water treatment, in flue gas desulphurisation, in construction and in agriculture. Agricultural lime (aglime), mainly ground dolomite and limestone, is used to control the pH of soil and to contribute nutrients (Ca and Mg) for plant growth.

A recent survey, of lime use throughout southern Africa (AUSTROPLAN, 1990), highlighted the priorities for the future development of lime production in the SADC (Southern African Development Community) region. The report concluded that Zambia has a surfeit of burnt lime (it is a net exporter to the region) but an inadequate production of aglime. Zimbabwe, on the other hand, has a well developed aglime industry but has a great need for indigenous production of high-quality calcitic burnt lime.

Natural development of industrial minerals builds from simple, small-scale production through to more complex, larger scales of production. Therefore, the development of lime production would ideally start with aggregate (crushed limestone) and aglime (crushed & ground limestone) progressing to burnt lime (crushed and calcined limestone) and cement (a mixture of limestone and other mineral inputs which are crushed, calcined and ground). Therefore, the current work focuses upon development of the aglime industry in Zambia (the principles of which could equally well be applied across the region and in part to burnt lime production).

As the first step in encouraging development of the aglime industry in Zambia, a survey of the state of the aglime market was carried out. The methods used and the findings of the survey are detailed in this report. This work forms part of the DFID/BGS TDR project "Local development of affordable lime in southern Africa" (R6492)

2. METHODS

The aims of the lime "market survey" were to determine the demand for lime, its quality, quantity and where it is most needed. Reviewing data and information from existing literature largely covered these. The quality of aglime was determined by firstly defining quality criteria and secondly by applying these criteria in a testing programme (covered in Sections C & D).

The actual usage of aglime, its cost and availability were also considered as part of the survey. This information was gathered via a questionnaire 'mailshot'. The questionnaire form contained a series of multiple choice questions, reproduced in Appendix A1.

In total, over 800 questionnaires were dispatched to farmers throughout the nine provinces of Zambia. Initially, contacts were made through the local representatives of the Zambia National Farmers Union (ZNFU). Approximately 1 in 10 of the questionnaires were returned, with most coming from the more commercially aware farming sectors in Lusaka and Southern provinces. No returns were received from Luapula and Western provinces. The number of returns do not allow a truly meaningful statistical analysis, however they do enable a 'snap shot' of the current use of aglime across Zambia.

3. RESULTS

3.1. Demand for lime

Recent estimates (Shitumbanuma & Simukanga, 1995) of the potential demand for aglime in Zambia are based on that required to control the soil acidity of currently cultivated land (mainly maize, groundnuts, soyabeans, sunflower and tobacco), estimated to be about 131, 000 tonnes. Also, that required to neutralise the acidity introduced by the use of NPKS (Nitrogen-Phosphorous-Potassium-Sulphur) fertilisers, estimated to be about 145, 000 tonnes per year. If the full agricultural potential of Zambia were to be realised then this figure would need to be multiplied by at least an order of magnitude. The current demand for aglime in Zambia has been estimated, by several authors over the last fifteen to twenty years, as follows:

Table A1. Actual, projected & potential demand for agricultural lime in Zambia

Source	**Demand for agricultural lime** (tonnes)
UNDP / UNIDO (1981)*	North-western Province 5,000 (potential) Northern Province 75,000 (potential)
Oygard (1987)	1985 10,000 (actual); 40,000 (potential)
AUSTROPLAN (1990)	1989 10,000 (actual) 1995 10,510 to 16,105 (projected) 2000 11,046 to 25, 937 (projected)
Shitumbanuma & Simukanga (1995)	1995 140,000 (potential)

* = United Nations Development Programme / United Nations Industrial Development Organisation

3.2. Quality of lime

In the United Kingdom, aglime has been defined as material containing "the necessary qualities to neutralize acidic soils, provide essential nutrients to promote plant growth and correct magnesium deficiency" (ARC, 1996). There are many forms of aglime, the simplest form being "ground limestone". The UK Agricultural Lime Producers Council (ALPC) list 20 varieties including ground limestone, screened limestone, limestone dust, magnesian ground limestone, chalk, ground chalk, ground burnt lime, kibbled burnt lime, hydrated lime and mixed lime (ALPC, 1996).

The effectiveness of agricultural liming material depends upon 'quality' criteria, such as:

i) Plant nutrient content. Typically expressed as weight percentages of calcium and magnesium oxide (CaO & MgO respectively). Magnesium is an important plant nutrient and therefore dolomite (Calcium magnesium carbonate, $CaMg(CO_3)_2$) is the preferred material for aglime production.

ii) Neutralisation ability, or neutralisation value (NV). Usually expressed as the weight percentage Calcium Carbonate Equivalent ($CaCO_3$ equivalent, or CCE). This is a measure of the base exchange (Ca & Mg) capacity of the liming materials for H^+ ions present in the soil. Pure limestone has a maximum NV of 100 % CCE and pure dolomite has a maximum NV of 108.6 % CCE. The NV can also be expressed on a calcium oxide (CaO) basis. Dolomite has a higher neutralization capacity than an equivalent amount of limestone due to its lower molecular weight. Dolomite also has an added benefit of contributing Mg to the soil although this is offset somewhat by its slower neutralization rate. Effective neutralisation value (ENV) is a measure of the acid-neutralizing capacity of ground lime and is a function of the CCE and the particle-size distribution.

iii) Agronomic effectiveness. Usually expressed as percentage reactivity. This is a measure of the ability of a fixed weight of ground carbonate to neutralise a fixed volume of acetic acid. A value of 100% represents complete neutralisation & lower values indicate incomplete neutralisation.

iv) Ease of pulverisation or grindability. Expressed as weight percentage finer than 75 μm. This is a measure of the ease with which a material, of a fixed sample weight under standard milling conditions, can be reduced to a powder. A carbonate with a high proportion of material finer than 75 μm indicates that it requires less energy to grind compared to carbonates with lower values.

To achieve maximum effectiveness the liming material must be ground to a relatively fine particle-size, this is particularly the case for harder material. The exceptions to this are burnt lime, (which breaks down in contact with water), and chalk, (a soft, porous carbonate that readily breaks down during cultivation). The proportion of material finer than 150 μm is considered critical in terms of performance. Typically, aglime contains up to 50 weight % <150 μm. Any material coarser than 600 μm is not effective unless it breaks down readily.

Oygard (1986) proposed that to be effective, finely ground aglime (i.e. 100% <2 mm & 50% <150 μm) is necessary for neutralization in the first year, whereas coarsely ground aglime (e.g. 100% <2 mm & 60% <400 μm) is necessary for longer term neutralization. As a compromise, Oygard suggested that an aglime containing 100% <2 mm and 30-60% <400 μm would perform adequately both over the short- and long-term.

Iin summary, the technical literature indicates the ideal aglime is a dolomitic or dolomitic limestone with a particle-size of 100% <2 mm, 60% <400 μm and up to 50% <150 μm.

3.3 Quantity of lime (lime production in Zambia)

Aglime production is mainly carried out in the provincial centres of Zambia. The largest producer is Ndola Lime Ltd, Ndola, whose primary role is the production of high calcium lime for use in copper processing. Its aglime is a by-product and represents the dust collected from the crushing plant. It is a calcitic lime and is widely utilised (mainly because it is cheap). Other producers include Mindeco Small Mines Ltd (calcitic & dolomitic lime), Crushed Stone Sales, Lusaka (calcitic and dolomitic lime), United Quarries, Lusaka (calcitic lime), and Lilyvale Farm, Kabwe (dolomitic lime). The average annual production of aglime in Zambia is estimated to be approximately 37, 000 tonnes (Shitumbanuma & Simukanga, 1995).

3.4. Where lime is most needed

The application of crushed limestone and dolomite is commonly used to ameliorate acid soils. Intensive methods of farming rely on the use of NPKS (Nitrogen-Phosphorous-Potassium-Sulphur) fertilisers. If these are continually added over many years, soil pH is lowered and becomes increasingly acid (<pH 4.5). A soil pH of <4.5 generally results in a drastic reduction in crop yield due to a combination of Ca and Mg deficiency and Al and Mn toxicity. If left unchecked, continued acidification of soil may eventually lead to desertification. However, soil pH can be regulated by the application of crushed limestone or dolomite, commonly known as aglime. The beneficial effects of aglime are threefold:

i) It neutralizes soil acidity,
ii) It increases the Ca and Mg available to plants as nutrients,
iii) It reduces availability of toxic Al and Mn to plants by making these elements less soluble

A single application of aglime every year is sufficient for the proper regulation of soil pH.

Soil acidity is a recognised problem in Zambia, especially in Northern, Luapula, Copperbelt and North-western provinces, areas of the country that experience high annual rainfall. A rainfall map of Zambia which delineates areas of high soil acidity is shown in

Figure A1. For purposes of comparison, outcrops of carbonate rocks are also featured. It is clearly evident that those areas in Zambia which receive average annual rainfall in excess of 1000 mm per year generally coincide with the zones of high soil acidity. The soil acidity of this region is an inherent problem, which is coupled with naturally low soil fertility. It is also clear that the central and southern provinces receive less rain and consequently their soils are less acid. These are also the areas of the best farmland and include the large scale commercial farms found alongside the rail line from Livingstone to the Copperbelt which use intensive farming methods.

Generally, commercial farmers are aware of the need to use aglime to maintain crop yields. However in the northern and western parts of Zambia subsistence and emergent farmers predominate who commonly employ the *Chitemene*, or 'slash-and-burn', type of shifting cultivation. These farmers use less intensive methods and are less aware of the rationale for the use of aglime. In *Chitemene* cultivation, branches are chopped from trees during the end of the dry season, between July and September, and laid out to dry. Before the start of the rains in November the wood is gathered into a heap and burnt. Crops (millet, groundnuts, beans and cassava) are grown in the ash for approximately 4-5 years until the ground is exhausted and the area is then left fallow for 20-30 years. However, increasing population pressure has resulted in longer cropping periods and shorter fallow periods, damaging crop yields (Matthews, 1997). Clearly, current *Chitemene* practice is not sustainable, as fallow periods are insufficient to allow the bush to regenerate to its original state, and if allowed to continue unabated will render large areas of Zambia unusable for future farming.

3.5. Questionnaire survey of aglime users

The results of the questionnaire survey are summarised in Table A2. Respondents invariably apply lime to their soils every 2 to 3 years, before ploughing or seeding, as a means of controlling soil pH. The majority of respondents follow Government guidelines by applying 1 to 2 tonnes of aglime per hectare. The price per 25 kg bag varies from less than 2000 Kwacha to greater than 5000 Kwacha and most respondents buy their lime direct from the lime production companies. Most respondents travel over 100 km to collect their lime and this is identified as the main problem with the use of aglime, along with the cost.

Table A2. Summary of lime questionnaire survey responses

Q1. Do you as a farmer use aglime ?		**Q5.** How much is a 25 kg bag of lime ?	
Every year	27	Less than 2000K	30
Every 2-3 years	47	2000-5000K	27
Never	24	More than 5000K	26
No answer	2	No answer	17
Q2. Why do you use lime ?		**Q6.** Where do you buy your lime from ?	
Prevent acid soil	81	Local store	9
As a fertiliser	2	Lime company	83
Both	4	Make it myself	0
No answer	13	No answer	8
Q3. When do you use lime ?		**Q7.** How far do you have to go to get lime ?	
Before ploughing	53	Less than 30 km	13
Before seeding	26	30-100 km	20
Both	3	More than 100km	59
Other	8	No answer	8
No answer	10		
Q4. How many tonnes of lime per hectare do you use ?		**Q8.** What are your problems with getting or using lime ?	
Less than one	20	Too expensive	13
One to two	63	Too far away	50
More than two	7	Both	13
No answer	10	No answer	24

4. DISCUSSION

4.1. Factors affecting demand for agricultural lime

The aim of the "market survey" was to assess the state of the aglime industry in Zambia. Is the conclusion of the AUSTROPLAN report correct? i.e. that aglime is the main priority for future lime production in Zambia. Considering that 'latent demand' for aglime, 140,000 tonnes pa, is far in excess of current production, approximately 37,000 tonnes pa and also that dolomitic carbonate deposits are widely available, the market for aglime in Zambia is evidently underdeveloped.

The factors that have led to this state are both social and economic. Lack of awareness of the need for liming is also a contributory factor. Many farmers would use lime if it were widely available at an affordable price. The main problem with the use of aglime was perceived by the consumers to be the long distance (typically over 100 km and in some cases over 800 km) from lime production centres to the farms. This introduces a transport factor that is the chief cause of the high cost of aglime at the point of use.

High transport costs are compounded by additional factors such as the lack of available credit facilities for buying lime as most farmers rely on credit to buy their major inputs such as fertilisers, seeds and pesticides. Also, intermittent production and the poor distribution from their suppliers discourage those commercial farmers who wish to purchase aglime. Frequently, lime is unavailable at the right time of year due to bad planning or lack of investment in plant. This has the consequence of shortages during periods of high demand. Demand for lime is cyclical and peaks in October and November, the months prior to seeding.

As stated earlier, many farmers in Zambia are unaware of the need to use aglime. Many of these prefer to continue with the traditional *Chitemene* cultivation practice. It has been reported that many extension workers of the Ministry of Agriculture choose not to educate farmers on the use of aglime (Shitumbanuma & Simukanga, 1995). They realise that only frustration will result when farmers either cannot afford or are unable to obtain aglime. Also, apparently, many extension workers share the common misconception that the use of fertiliser and aglime are interchangeable, and mistakenly believe that application of fertiliser will improve soil acidity. The situation is further exacerbated by a host of other factors such as the lack of marketing by producers, the lack of information regarding quality and use; and poor packaging and labelling of products

In order to reduce the transport cost factor aglime would have to be produced closer to the point of use. This highlights one of the dilemmas affecting aglime production in Zambia. Currently aglime is only produced in a few centralised plants and their combined production is assumed to satisfy the perceived demand for aglime. Additional aglime plants are not considered economically viable due to the small perceived demand in the outlying provinces. However, demand is suppressed by the high cost of aglime. If additional plants were commissioned, consumption would undoubtedly increase due to the lower cost of aglime to local consumers. However, 'breaking' into this cycle would require a brave producer with readily available capital, or innovative thinking, e.g. small-scale low cost production methods that could cheaply and easily be implemented.

4.2. Local production of agricultural lime

Several studies have been undertaken over the last 15 years attempting to address the problem of soil acidity in Zambia (UNDP / UNIDO, 1981; Oygard, 1987; AUSTROPLAN, 1990). These studies have recommended the establishment of limestone crushing plants at the following strategic localities to meet the aglime requirements of:

Chivuna, Southern Province	Mkushi, Central Province
Nyimba, Eastern Province	Isoka, Northern Province
Matanda, Luapula Province	Solwezi, North-western Province

Of the remaining three provinces, Lusaka and Copperbelt Provinces are already well served, and Western Province appears to lack the necessary carbonate resources. However the failure to implement the proposed Chivuna lime project has revealed a number of possible flaws in this strategy.

i) Prohibitive capital and operating costs. For example the typical total costs for the purchase and installation of each crushing plant exceeds US$750, 000. Maintenance and operation of sophisticated plant is also costly, especially if run below full capacity.

ii) Lack of infrastructure, including the training of manpower, provision of adequate power and water resources.

Many of the studies acknowledge that a large proportion of the selling price of aglime is the cost of transportation. At present this is particularly true of those areas far removed from the production centres, which are generally the areas that have the greatest need for liming. For example the December 1996 price of aglime direct from Lilyvale Farm, Kabwe was 950 kwacha per 50 kg and from Ndola Lime, 2200 kwacha per 25 kg bag. The price from a supplier in Solwezi (approximately 300 km NW of Ndola) was 5500 kwacha per 25 kg bag. This represents a price increase of 150%. (Incidentally, at this time this was academic as the aglime supplier had been out of stock for many weeks). Improvements in the road and rail infrastructure have also been proposed and would be of some benefit. However, in addressing the issue of transport costs, previous studies have generally suggested that they be offset by introduction of subsidies. This is somewhat naive given the political context in which other agricultural subsidies are actually being reduced.

The current volume of aglime production is also much smaller than the potential demand. This effective lack of demand further undermines the rationale for establishing provincial lime crushing plants, as only 10 to 20, 000 tonnes per year per plant would be required. These modern crushing plants would be operating at low capacity whereas they are most efficient when operating at full capacity. This would result in unacceptably high production costs.

It has been argued that establishment of crushing plants will stimulate the more widespread use of aglime. This is because increased availability and the consequent tangible benefits arising from aglime use would stimulate demand. As production rose economies of scale would increasingly lower the price of lime encouraging more farmers to use it. This is referred to as a 'virtuous circle' in which demand-led production ultimately results in widely available low-cost aglime. Currently the opposite is true, i.e. a situation exists in which demand is stagnant and depressed due to lack of availability and high transport costs.

It is possible that a "grassroots" approach, involving the local, small-scale production of aglime adjacent or close to the areas of need, would stimulate demand both by increasing availability and reducing the predominant transport cost element, thereby creating a "virtuous circle" of increased usage and reduced costs. Also, use of an appropriate level of technology and local labour (ideally drawn from the farming community) would lower production costs. It is possible that that local peasant farming co-operatives could manage these aglime facilities and co-ordinate lime production to best suit their members. Costs could be offset to some extent by sale of excess production where necessary.

The feasibility of small-scale lime production has been investigated as part of the project. The location of suitable limestone and dolomite is covered in sections B, C & D, whereas the methods of producing lime on a small-scale are covered in sections E & F. Successful development of small-scale lime production could eventually stimulate demand to the extent that the larger scale production, envisaged by others, would become justified.

5. CONCLUSIONS

i) A survey was carried out to determine the state of the aglime market in Zambia. The aim of the survey was to determine the demand for lime, its quality, quantity and where it is most needed. This was achieved by reviewing existing literature and a questionnaire mailshot.

ii) The latent demand for aglime in Zambia is put at approximately 140,000 tonnes (at current levels of cultivation). This would be required to neutralise the natural acidity of the soils of northern Zambia and that introduced through the use of fertilisers.

iii) The quality of aglime can be expressed in terms of its plant nutrient content (CaO + MgO content), its Neutralisation Value (NV), its agronomic effectiveness (reactivity) and ease of pulverisation, or grindability.

iv) Current production of aglime in Zambia is approximately 37,000 tonnes pa.

v) Large parts of Zambia suffer from the problem of low crop yield due to soil acidity caused by high rainfall. Pressure on traditional cultivation systems (especially *Chitemene*), as well as the use of fertilisers have further exacerbated soil acidity and the need for its amelioration.

vi) Consumers typically apply 1-2 tonnes of aglime per hectare every 2 to 3 years before ploughing as a means of controlling soil pH. The price per 25 kg bag varies from less than 2000 Kwacha to over 5000 Kwacha. The main problems with supply of aglime are perceived to be the long distances from supplier to point of use, as well as cost.

vii) In many areas, the usage of aglime is stagnant and depressed due to lack of availability and high transport costs. This has resulted in a gradual decline in agricultural production as soil acidity worsens.

viii) It is possible that a "grassroots" approach, involving local, small-scale production of aglime, adjacent or close to areas of need, would stimulate demand by increasing availability and reducing the predominant transport cost element, thereby creating a “virtuous cycle” of increased usage and reduced costs. The feasibility of establishing this type of small-scale production is being pursued as part of this project.

APPENDIX A:1

QUESTIONAIRE ON THE USE LIME IN ZAMBIAN FARMING

This is to find out about the use of agricultural lime as part of work carried out with Zambian Ministries of Mines and Mineral Development & Agriculture

Please tick the box that applies to you ✓

1	**Do you as a farmer use agricultural lime ?**	**Every year**	**Every 2 - 3 years**	**Never**
2	**Why do you use lime ?**	**Prevent acid soil**	**As a fertiliser**	**Do not know**
3	**When do you use lime ?**	**Before ploughing**	**Before seeding**	**Other**
4	**How many tonnes of lime per hectare do you use ?**	**Less than one**	**One to two**	**More than two**
5	**How much (in Kwacha) is a 25 kg bag of lime ?**	**Less than 2000**	**2000 to 5000**	**More than 5,000**
6	**Where do you buy your lime from ?**	**Local store**	**Lime company**	**Make it myself**
7	**How far do you have to go to get lime ?**	**Less than 30 km**	**30 to 100 km**	**More than 100 km**
8	**What are your problems with getting or using lime ?**	**Too expensive**	**Too far away**	**Don't know why I should use it**

Please use the addressed FREEPOST envelope provided (this has been accepted as vaild postage)
To be fully sure that it does reach the UK please add stamps (approx 900 Kwacha) to envelope provided .
1000 Kwacha will be refunded upon receipt.

APPENDIX A:2
SELECTED COMMENTS ARISING FROM AGLIME SURVEY

i) "...the most significant aspect of rural agriculture, and the most neglected, is lime...."
(Respondent No. 1)

ii) "....currently lime is purchased from Kabwe, over 200 km from Mazabuka, yet there are good limestone deposits in Mazabuka...."
(Respondent No. 2)

iii) "......the transport cost from Kabwe, where the most reliable firm is situated to the Southern province, is prohibitive......."
(Respondent No. 10)

iv) ".....the other problem is education on lime......"(Respondent No. 13)

v) "....tobacco can warrant the expense of magnesium sulphate, but to make the project more viable it would be better if the lime had wider appeal & had a higher Mg content...."
(Respondent No. 13)

vi) ".....the problem of a cheap affordable source of affordable agricultural lime is a long standing one and is of vital importance to Southern province where pH has become dangerously low. This was aggravated on large scale farms by the wide spread use of sulphate of ammonia....."
".....nearest source of agricultural lime is Kabwe 600 km away so mileage far exceeds the cost of lime....."
(Respondent No. 17

vii) ".....Northern province lime comes from Kabwe 700 km away or Ndola 800 km away......"
(Respondent No. 25)

viii) ".... for many years yields have been very poor to such levels that call for concern...."
(Respondent No. 33)

ix) "....the problem of liming in this country is the inadequate supply of lime from basically the companies that do agricultural lime...."
(Respondent No. 34)

x) "....We use it because we have to but it is too expensive and too far away...."
(Respondent No. 35)

xi) "....nearest source of lime is Lusaka which is prohibitively expensive for the small-scale farmer...."
(Respondent No. 39)

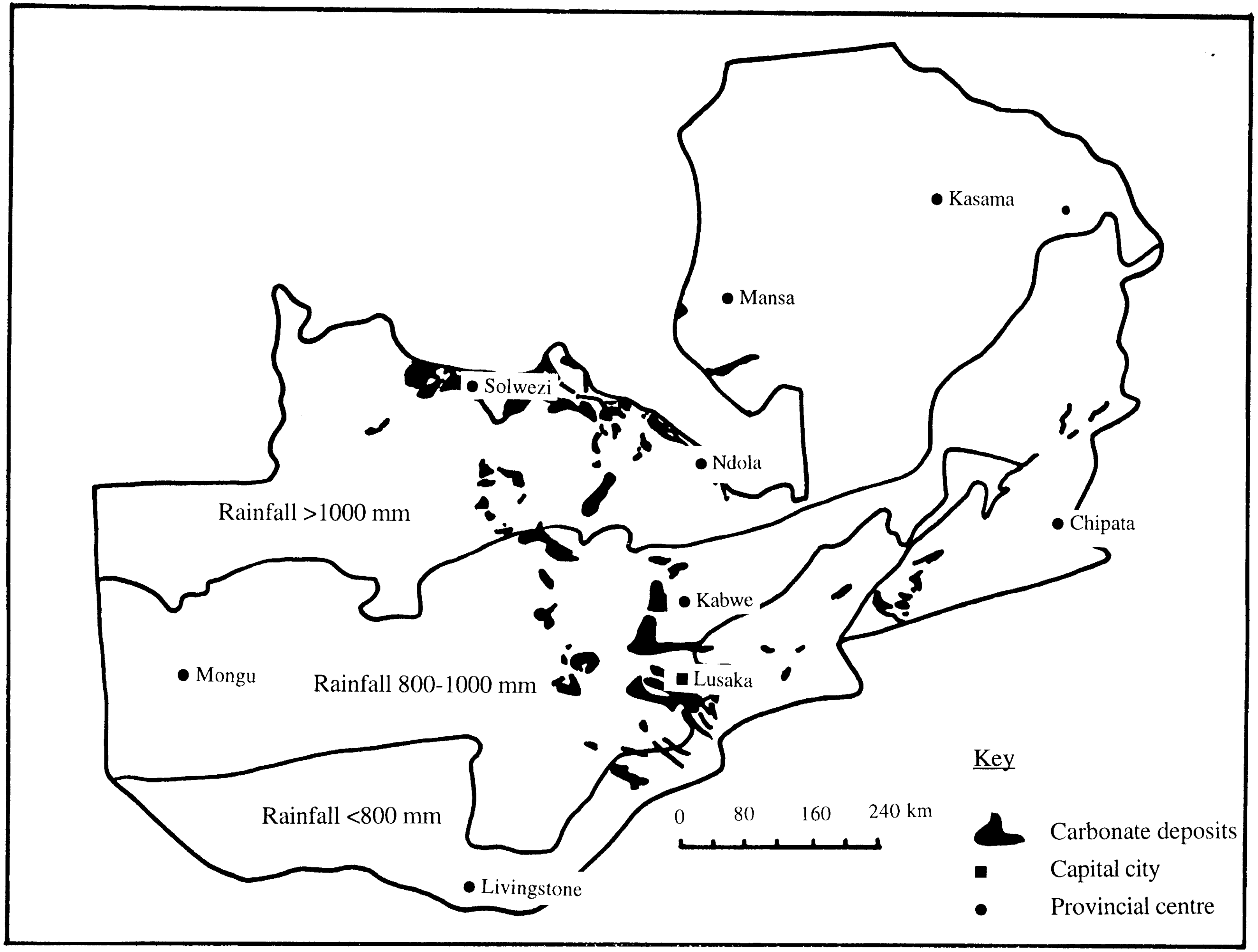

Figure A1 Rainfall map of Zambia; overlain by limestone & dolomite occurrences (after Veldkamp, 1987 and Simukanga et al, 1993)

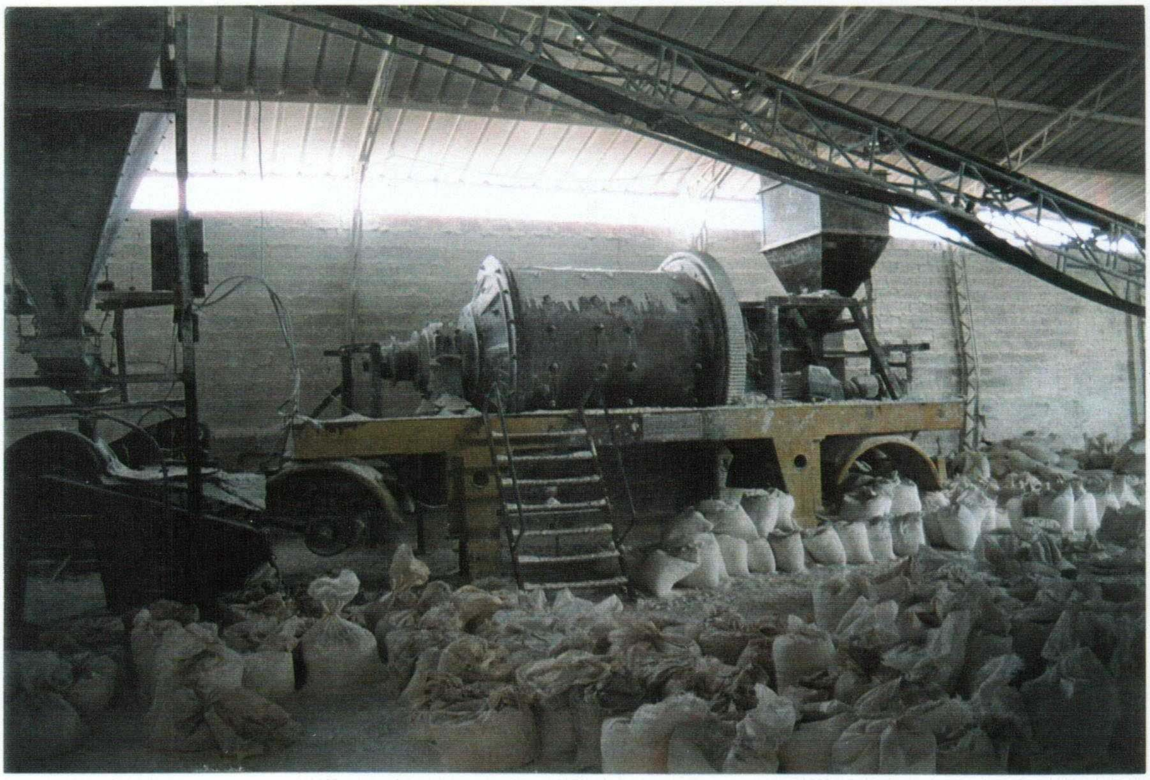

Plate A1. Ball milling of agricultural lime, Mindeco Small Mines Ltd, Lusaka

Plate A2. Calcitic (dark grey) & dolomitic (light grey) carbonate, Ndola Lime Ltd

SECTION B:
REVIEW OF THE CARBONATE RESOURCES OF ZAMBIA

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British Geological Survey, UK

1. CARBONATE GEOLOGY OF ZAMBIA

A summary of the stratigraphic succession in Zambia is provided in Appendix B1. A comprehensive list of the principal carbonate resources of Zambia is provided in Appendix B2. Sources of information on the carbonate resources of Zambia are provided in Appendix B3. The geographical distribution of the carbonate rocks in Zambia is summarised in Fig. A1 (Section A).

1.1. Basement complex

Zambia is underlain by a crystalline basement complex of Lower Precambrian age, which is extensively exposed in the east and south-east. Towards the west the basement is overlain by an increasing thickness of a younger sedimentary sequence. The Lower Precambrian basement complex can be subdivided into the older Lufubu (metamorphic basement terrain) and the younger Muva Supergroup (metasedimentary and metavolcanic sequences).

The carbonates of the Lufubu are poorly documented. Deposits occur in Lusaka, Central, Southern & Eastern provinces. They consist of fine to coarsely crystalline calcitic to dolomitic marbles; grey, white or pink in colour with occasional banding.

The carbonates of the Muva Supergroup occur in six groups in Northern, Eastern, Central & Lusaka provinces. The Mpanshya & Sasare Groups consist of thinly banded dolomitic marbles and calc-silicates. The dolomitic marbles range in colour from white, buff, grey, green to blue and are often impure in composition. The Fombwe and Lusandwa Groups (Lusandwa may be an old name for the Fombwe) consist of white coarsely crystalline dolomitic & calcitic marble, with occasional calc-silicate rocks. The marbles occur as lenses and bands in granulite and gneiss. The Manshya and Kafue Groups consist of limestone and dolomitic marble bands, often foliated and recrystallised. Typical chemical analyses are given in Table B1.

Table B1. Chemistry of Basement complex marbles, Zambia

Stratigraphy	**CaO** (wt %)	**MgO** (wt %)	**Insoluble residue** (wt %)	**Fe_2O_3** (wt %)
Unknown - Lusandwa river area (Msoro)	41.4	7.7	9.2	0.4
Unknown - Lusandwa river area (Ukwimi)	48	4.3	3.9	0.25
Sasare Group - Sasare area	38.1	12.6	4.5	0.5

Source : Bosse, 1996

1.2. Katanga Supergroup

1.2.1. Geology

The basement is overlain unconformably by the Upper Precambrian Katanga Supergroup (clastic and carbonate sequences), which occurs in the northern, north-western, southern and central parts of Zambia. The Katanga is sub-divided as follows: Lower Katanga, including the Monze, Broken Hill and Mine Series groups; Middle Katanga, the Mwashia Formation; and the Upper Katanga, the Kundelungu Group.

1.2.2. Monze Group

The Monze Group contains seven formations. The Kaleya Formation (Kaleya Limestone) consists of impure, thinly bedded dolomitic marls. The Muzuma Formation contains intercalations of marble in calc-silicates. The Chifumpu (Chifumpu Limestone), Chafugoma (Wamikumbi or Mujimbeji Marble), Chivuna (Chivuna Limestone), Ngoma and Nadongo formations all consist of medium to coarse grained, massive to banded dolomitic and calcitic marbles. They are white. pink, brown, grey to grey-blue in colour, often impure and occasionally silicified. The dolomitic carbonates that occur at Chivuna contain 24.6 to 30.4% CaO and 21.8 to 25.7% MgO. Typical chemical analyses are given in Tables B2 and B3.

The aglime (aglime) potential of NW province is considered by Rao (1984). The main carbonate occurring in this area is the Mujimbeji Marble (Chafugoma Formation, Monze Group, Katanga) which consists of grey, grey-blue & white, medium to coarse grained banded calcitic marbles interbedded with brown fine grained dolomitic marbles within mica schist. Typical chemical analyses are given in Table B3.

Table B2. Chemistry of Monze Group carbonates, Zambia

Stratigraphy	CaO (wt %)	MgO (wt %)	Insoluble residue (wt %)
Kaleya Formation			
- Magoye & Gwembe area (NE Monze)	42.0	14.2	7.0
Chifumpu Formation			
- Magoye & Gwembe area (NE Monze)	41.6	8.3	8.6
Chivuna Formation			
- Magoye & Gwembe area (NE Monze)	30.1	22.0	0.3
Nadongo Formation			
- Magoye & Gwembe area (NE Monze)	42.6	3.9	13.4
- Choma & Gwembe area (E Monze)	51.7	na	7.0
Lower Katanga			
- Chikankata area	46.1	1.2	15.3
	31.1	16.9	9.2
Muzuma Formation			
- Chikankata area	46.4	0.6	16.0

Source: Bosse, 1996 na = not available

Table B3. Chemistry of Mujimbeji Marble, NW Province, Zambia

Lithology	CaO (wt %)	MgO (wt %)	Fe2O3 (wt %)	MnO2 (wt %)
Calcitic marble	40.9 to 54.0	2 to 10.3	0.001 to 0.03	0 to 0.02
Average	48.1	4.0	0.01	0.004
Dolomitic Marble	23.8 to 40.2	3.4 to 22.5	0.003 to 0.86	0.002 to 0.08
Average	29.4	18.2	0.12	0.02
Brecciated Limestone	15.7 to 48.0	0.2 to 13.3	0.001 to 1.47	0.002 to 0.35
Average	34.9	3.5	0.55	0.06
Calcrete	65.7 to 51.4	2.8 to 5.4	0.001 to 5.15	0.03 to 1.04
Average	23.7	4.0	1.86	0.27
Argillaceous Limestone	2.0 to 21.2	2.6 to 15.5	0.01 to 8.87	0.002 to 12.86
Average	10.3	8.7	3.48	1.51

Source: Rao, 1984

1.2.3. Broken Hill Group

The Broken Hill Group contains the Lusaka, Mampompo (Cheta) and Matero (Chunga) formations, or the Lusaka Dolomite, Mampompo Limestone and Luimba Limestone respectively. These all consist of fine to coarse grained, banded to massive dolomitic and calcitic marbles. They are white, pink, grey to grey-blue in colour, with occassional calc-silicate rocks. Typical chemical analyses are given in Table B4.

Table B4. Chemistry of Broken Hill Group carbonates, Zambia

Stratigraphy		CaO (wt %)	MgO (wt %)	Insoluble residue (wt %)	Fe_2O_3 (wt %)
Lusaka Formation					
- Lusaka area		53.0	1.5	1.0	0.1
- Monze area (SW Mazabuka)	min.	28.7	0.3	1.8	na
	max.	53.7	20.8	18.7	na
	av.	37.2	11.3	7.7	na
- Mwembeshi river area		42.0	10.0	na	na
		51.0	3.0	na	na
Mampompo Formation					
- Leopards Hill area	min.	49.2	0.4	0.8	0.7
	max.	53.5	2.0	6.3	3.0
	av.	51.3	0.9	3.2	1.7
- Lusaka area		54.7	0.3	0.7	na
		48.0	na	na	3.5
		28.0	20.6	5.6	na
- Mwembeshi river area		33.0	20.0	na	na
Matero Formation					
- Mwembeshi river area		30.0	20.0	na	na
		51.0	2.0	na	na
- Lusaka area (Chalimbana)		54.1	<0.7	na	na

Source: Bosse, 1996 na = not available

1.2.4. Mine Series Group

The Mine Series Group contains the Upper and Lower Roan formations, which consist of fine, grained, banded dolomitic marbles. They are white, pink, brown to grey in colour, often impure and occasionally silicified.

Rao (1987) considered the aglime potential of the area around Mpongwe (Copperbelt Province). The main carbonates occurring in this area are of the Upper Roan Formation (Mine Series Group, Katanga) and consist of white, grey, brown to pink, fine grained dolomitic marbles. They occur near Chinwa stream, between Kashinga village & Kanyenda school, adjacent Mkubwe road, in St. Anthony's mission area, in Lake Kashiba & Lake Nampamba areas and east of the Mpongwe company. Typical chemical analyses are given in Table B5.

Table B5. Chemistry of marble, Upper Roan Formation, Mpongwe area, Copperbelt Province

Lithology	**CaO** (wt %)	**MgO** (wt %)	**NV**
Dolomitic marble	28.62 to 55.86	0.40 to 27.72	84 to 133

Source: Rao, 1987 NV = Neutralizing value expressed as % calcium carbonate equivalent (CCE)

1.2.5. Mwashia Formation, Middle Katanga

The carbonates of the Mwashia Formation are only known to occur in Central Province and consist of white, pink to brown, fine to coarse grained dolomitic marbles and grey, coarse grained calcitic marbles. Typical chemical analyses are given in Table B6.

Table B6. Chemistry of Mwashia Formation carbonates, Zambia

Stratigraphy		**CaO** (wt %)	**MgO** (wt %)	**Insoluble residue** (wt %)
Broken Hill dolomite				
- Luiri Hill area	min.	53.3	0.3	0.8
	max.	54.4	1.9	8.0
	av.	54.0	1.0	1.7
		27.7	15.9	17.2

Source: Bosse, 1986

1.2.6. Kundelungu Group

The carbonates of the Kundelungu Group are reported to occur in North-western, Copperbelt, Central, Lusaka and Southern Provinces. The Lower Kundelungu Formation, known as the Kakontwe Limestone, consists of fine to coarse grained, white to blue-black dolomitic marbles and fine to coarse grained, blue-black, banded calcitic marbles. The West Lunga Formation consists of grey, grey-green to white, fine to coarse grained banded calcitic marbles and grey, brown to purple-brown, fine to medium grained dolomitic marbles. Dolomitic calcite and calcitic dolomite marbles also occur. The Nyama Formation, known as the Muchinda Limestone, consists of white, grey, blue-grey to pink, fine grained banded dolomitic marbles and white to grey, coarse grained, banded calcitic marbles. The Upper Kundelungu Formation, also known as the Luapula Beds (contains the Matanda and Bukanda limestone), consists of hard, blue to pink, laminated or massive dolomitic marble interbedded with shales, sandstone and conglomerate. The Kaosna Formation consists of buff, fine grained conglomeratic marble with clasts of quartz, phyllite, sandstone and carbonate. The Kanyidma Formation consists of grey, grey-green to pink, fine grained, compact, brittle argillaceous to pure calcitic marble. Typical chemical analyses are given in Tables B7, B8 and B9.

Table B7. Chemistry of Kundelungu Group carbonates, Zambia

Stratigraphy		**CaO** (wt %)	**MgO** (wt %)	**Insoluble residue** (wt %)	**Fe_2O_3** (wt %)
Upper Kundelungu Formation					
- Bukanda, Mansa		27.8	17.4	7.5	2.6
- Matanda, Mansa		28.5	18.4	10.8	1.1
Lower Kundelungu Formation					
- Ndola area					
(calcitic limestone)	min.	47.8	0.1	0.2	0.3
	max.	54.9	5.8	7.0	1.2
(dolomitic limestone)	av.	52.2	1.6	2.4	0.6
	min.	30.3	20.2	0.1	0.1
	max.	31.1	21.3	1.9	0.7
	av.	30.7	20.8	0.6	0.3
Nyama Formation					
Chisamba area (SW of Kabwe)		38.9	0.7	23.8	na
		52.0	0.1	4.5	na
- S of Lukanga swamp area		49.8	0.9	na	na
		30.1	16.0	na	na

Source: Bosse, 1996 na = not available

Okill (1984) considered the aglime potential of Luapula Province. The main carbonates occurring in this area are known as the Luapula Beds (Upper Kundelungu Formation, Kundelungu Group, Katanga). They consist of hard, blue to pink, laminated or massive dolomitic marbles interbedded with shales, sandstone and conglomerate. They occur near Matanda (south west of Mansa), adjacent Bukanda stream (west of Mansa), near Kaniembe and Kosamu. The dolomitic marble at Matanda has a neutralization value of approximately 100 % CCE (Oygard, 1987) Typical chemical analyses are given in Table B8.

Table B8. Chemistry of dolomitic marble (Luapula Beds), Luapula Province

Lithology	**CaO** (wt %)	**MgO** (wt %)	**Fe2O3** (wt %)	**Al2O3** (wt %)	**SiO2** (wt %)	**Mn** (wt %)
Dolomitic marble	27.9 to 31.3	15.5 to 19.30	0.5 to 2.9	0.4 to 0.5	9.1 to 16.8	0.4 to 0.5
Average	28.6	17.8	1.6	0.4	12.8	0.5

Source: Okill, 1984

The Geological Survey Department prepared a report on the suitability of the dolomitic carbonates to the NW of Mkushi (Carruthers, 1986). The dolomite occurs as part of the Kundelungu Group (although its exact stratigraphy remains unresolved). The carbonate is a pale grey, pink to white, fine-grained banded dolomitic marble with little variation which grades into silicified marble. The dolomite has come under the focus of the Mkushi Small Farmers Association, who are actively engaged in promoting its exploitation as aglime. Typical chemical analyses are given in Table B9. The neutralization values range from 79 to 107 % CCE (Oygard, 1987).

Table B9. Chemistry of dolomitic carbonate, Mkushi

Sample	CaO (average wt %)	MgO (average wt %)	Insoluble residue (average wt %)	Fe_2O_3 (average wt %)
Orientation chips	28.2	20.6	4.6	1.2
Rock samples	31.3	17.2	9.3	0.8

Source: Carruthers, 1986

1.2.7. Undifferentiated Katanga

Several significant carbonate groups, classified as "undifferentiated Katanga", occur in Central, Eastern, Southern and Lusaka provinces. The Mvuvye Group, known as the Mvuvye Marble, consists of white, grey, bluish grey, yellowish-brown, brown to pink, fine to coarse grained, hard, compact dolomitic marble with occassional calc-silicates. The Kangomba Formation consists of banded dolomitic marbles. The Mapanza Carbonate Formation consists of white, grey to cream, medium to coarse grained, hard to compact, banded calcitic marble. Varieties include brown micaceous friable marble and grey banded marble. The Upper Chilembwe Formation, known as the Chilembwe Schist, consists of white to grey, fine to coarse grained calcitic marbles with locally developed white to pink, fine to coarse grained dolomitic marble. Limestone and dolomite are also recorded in the Mazabuka Group. A limestone horizon was also reported occurring at Masangu Farm (SE of Mazabuka) that consists of white, coarse grained, sugary textured massive calcitic marble. Limestone and dolomite bands are also recorded as occurring in pelitic schists and psammites, for example within the Chipongwe psammite. Typical chemical analyses are given in Tables B10, B11, B12 and B13.

Table B10. Chemistry of the undifferentiated Katanga carbonates, Zambia

Stratigraphy		CaO (wt %)	MgO (wt %)	Insoluble residue (wt %)	Fe_2O_3 (wt %)
Mapanza Carbonate Formation					
- Mapanza Mission area (W of Monze)	min. max. av.	42.4 52.5 49.3 28.8	0.2 0.9 0.5 17.0	4.4 20.7 10.0 10.2	0.3 1.8 0.9 2.9

Source: Bosse, 1996

The aglime potential of the Macha-Mapanza Mission areas was considered by Simasiku (1986). The main carbonates occurring in this area are of the Mapanza Carbonate Formation (Undifferentiated Katanga). They consist of white, grey to cream, medium to coarse grained, hard to compact, banded calcitic marble (with friable micaceous, and grey banded varieties). They occur in the following areas: Mapanza, Chikwayi, Munyeke-Macha, Hanjabu and Dundwa. Typical chemical analyses are given in Table B11.

Table B11. Chemistry of calcitic marble, Mapanza Carbonate Formation, Macha-Mapanza Mission, Southern Province

Lithology	CaO (wt %)	MgO (wt %)	Fe2O3 (wt %)	MnO2 (wt %)
Calcitic marble	28.8 to 52.1	0.5 to 9.0	0.3 to 2.0	0.02 to 0.09
Average	41.6	3.3	1.0	0.03

Source: Simasiku, 1986

The aglime potential of the Nyimba area (Eastern Province) was considered by Rao in 1986 (Hofmeyer Mission area) and Simasiku in 1986b (Nyimba area). The main carbonate occurring in this area is the Mvuvye Marble (Mvuvye Group, Katanga). It consists of white, grey, bluish-grey, yellowish-brown, brown to pink, fine to coarse grained, hard and compact dolomitic marble (with occasional calcitic marble). It occurs in the area to the SE of Hofmeyer Mission, SE of Nyimba, S of Nyimba and around Nyimba town. Typical chemical analyses are given in Table B12.

Table B12. Typical chemistry of Mvuvye Marble, Nyimba area, Eastern province

Lithology	CaO (wt %)	MgO (wt %)	MnO2 (wt %)	Fe2O3 (wt %)
Nyimba Dolomitic marble	23.1 to 32.6	19.8 to 33.2	0.1 to 0.7	0.5 to 1.5
Average	28.1	27.5	0.3	1.0
Nyimba Calcitic marble	28.6 to 53.8	0.3 to 12.2	0.02 to 0.3	0.3 to 5.9
Average	41.8	2.0	0.1	1.5
Hofmeyer Mission Calcitic marble	4.5 to 55.0	0.2 to 21.9	0.02 to 0.24	0.2 to 2.9
Average	28.7	9.8	0.07	0.6

Source: Rao, 1986; Simasiku, 1986b

The Geological Survey Department (GSD) prepared a feasibility study on the suitability of limestone from Masangu Farm, SE of Mazabuka for use as aglime (Liyungu, 1995). The limestone occurs as part of the Katanga Supergroup (although its exact stratigraphy remains unresolved). The limestone occurs as a coarse-grained, white to yellowish-grey calcitic marble with a sugary texture. The chemistry is given in Table B13.

Table B13. Chemistry of limestone, Masangu Farm

Lithology		CaO (wt %)	MgO (wt %	SiO_2 (wt %)	Fe_2O_3 (wt %)
Calcitic dolomite	min.	36.9	0.6	5.55	1.2
	max.	51.9	1.4	24.84	2.4
	av.	44.8	1.0	15.2	1.8

Source: Liyungu, 1995

1.2.8. Commercial extraction from the Katanga

Chilanga Cement Ltd exploits the calcitic marble of the Mampompo Limestone for the production of cement. The Mampompo limestone is also exploited by Crushed Stone Sales Ltd, United Quarries Ltd and Mindeco Small Mines Ltd for the production of ground limestone. The calcitic marble of the Lower Kundelungu Formation is exploited by Ndola Lime Ltd for the production of burnt lime and by Chilanga Cement (Ndola) Ltd for the production of cement. Typical chemical analyses are given in Table B14.

Table B14. Chemistry of commercial limestone products, Zambia

Stratigraphy	CaO (wt %)	MgO (wt %)	SiO_2 (wt %)	Fe_2O_3 (wt %)
Chilanga cement				
- Chilanga	48.6	1.0	7.6	1.4
- Ndola	53.3	0.5	1.2	0.3
Crushed Stone Sales Ltd				
- calcitic	47.4	2.8	6.4	0.5
- dolomitic	44.0	11.0	0.9	0.4
United Quarries Ltd	52.0	2.4	2.2	0.1
Lilyvale Farm, Kabwe	na	25.8	na	na
Mindeco Small Mines Ltd	50.4	1.8	na	0.1

Source: Austroplan, 1990; Briggs & Mitchell, 1991; na = not available.

1.3. Post Katanga

The Katanga Supergroup is overlain by Lower Palaeozoic rocks, which are only proved in boreholes in western Zambia and consists mainly of quartzites, shales and arkoses. No carbonates are recorded.

The Karoo Supergroup (Carboniferous to Lower Cretaceous) occurs in the rift valleys and in western Zambia, and is sub-divided into Lower and Upper Groups (sedimentary and volcanic sequences). The Madumabisa Formation occurs in Southern Province and contains blue-grey, brown to green, fine grained massive argillaceous limestones intercalated with mudstone and sandstone.

The Kalahari Group (Late Tertiary to Recent) covers a large part of western Zambia. It can be sub-divided into the older Barotze Formation and the younger Zambezi Formation (clastics and carbonates). The Barotze Formation contains reddish-brown to yellowish-brown, medium grained, compact granular silicified lacustrine limestone. The Zambezi Formation contains calcrete. Alluvium occurs mainly along the courses of the upper Zambezi, the Kafue flats, Lukanga and Bangweulu swamps, and along the upper-Chambeshi river. No carbonates are recorded.

1.4. Miscellaneous

Carbonatites occur in Northern and Eastern provinces. The most significant of these is the Nkombwa Hill carbonatite occurring near Isoka in Northern province. It contains dolomitic, silicified, ankeritic and pure carbonatite. The dolomitic carbonatite is white, grey to brown, banded to massive, coarse grained with veins of ankerite. Several carbonatites occur in Eastern province, notably at Kaluwe and Chasweta. Chemical analyses are given in Tables B15 and B16. Travertine is also recorded occurring NW of Luangwa in Eastern Province.

Table B15. Chemistry of carbonatites, Zambia

Location		CaO (wt %)	MgO (wt %)	Fe_2O_3 (wt %)	MnO (wt %)
Kaluwe	min.	35.9	0.4	0.1	2.8
	max.	48.6	0.7	1.3	11.0
	av.	43.8	0.6	0.5	6.3
Chasweta		41.5	2.0	9.0	2.2

Source: Bosse, 1996

Nalluri (1984) considered the aglime potential of Nkombwa Hill (Northern Province). The main carbonate occurring in Nkombwa Hill is carbonatite, of which there are four main varieties: dolomitic carbonatite with phlogopite, silicified carbonatite, carbonatite and pure ankeritic carbonatite. The dolomitic carbonatite was the only unit considered suitable for use as aglime. It consists of white, grey to brown, fine to coarse grained, banded to massive carbonatite with veins of ankeritic carbonatite and zones of pegmatitic carbonatite. The carbonatite has low neutralization values, approximately 80 to 90 % CCE, which would mean that up to 20% extra would be required to have the same effect as purer carbonates (Oygard, 1987). Typical chemical analyses are given in Table B16.

Table B16. Typical chemistry of dolomitic carbonatite, Nkombwa Hill, Isoka, Northern Province

Lithology	CaO (wt %)	MgO (wt %)	MnO2 (wt %)	Fe2O3 (wt %)	P2O5 (wt %)
Dolomitic carbonatite	5.0 to 40.5	10.4 to 30.2	0.2 to 2.4	0.6 to 14.3	0.2 to 31.5
Average	24.0	19.0	1.2	4.7	4.8

Source: Nalluri, 1984

1.5. Occurrences of limestone with potential for use as agricultural lime

Geographically, carbonate rocks are generally concentrated in central Zambia, with the remaining provinces containing fewer carbonate resources (with no significant resources in Western province). In terms of chemical composition, the basic requirement for aglime is a minimum MgO content of 6% (Tether & Money, 1989). On this basis, using the chemical data collated for this report, the carbonate resources of Zambia can be screened as to their potential suitability for use as aglime. Table B17 lists those carbonates that meet this basic requirement.

Table B17. Potential sources of limestone & dolomite for agricultural lime in Zambia.

Lithostratigraphy	MgO (average wt %)	CaO (average wt %)	Locality
Basement			
- Unknown	7.7	41.4	Msoro
- Sasare Group	12.6	38.1	Sasare
Lower Katanga Supergroup			
- Kaleya Form.	14.2	42.0	NE of Monze
- Chafugoma Form.	29.4	18.2	Solwezi area
- Chifumpu Form.	8.3	41.6	NE of Monze
- Lusaka Form.	11.3	37.2	SW of Mazabuka
- Upper Roan Form.	up to 27.7	up to 55.9	Mpongwe area
- Lower Roan Form.	19.8	28.9	Mkushi
Middle Katanga Supergroup			
- Broken Hill dolomite	15.9	27.7	Luiri Hills
Upper Katanga Supergroup			
- Upper Kundelungu Formation	17.9	28.2	Mansa area
- Lower Kundelungu Formation	20.8	30.7	Ndola area
Undifferentiated Katanga			
- Mvuvye Marble	27.5	28.1	Nyimba
Carbonatite			
- Nkombwa Hill	19.0	24.0	Isoka area

A more detailed description of the limestones and dolomites listed in Table B17 (and other carbonates), is provided in Appendix B4 including brief lithological details and geological map sheet numbers. The sources of limestone and dolomite identified in Table B17 and Appendix B4, and their proximity to areas of soil acidity, were used to plan a programme of fieldwork undertaken as part of this project (Section D).

2. CONCLUSIONS

Carbonate rocks occur widely throughout Zambia, particularly in Southern, Eastern, Central, Lusaka, Copperbelt and North-western Provinces. Luapula and Northern Provinces have only limited occurrences and Western province has no significant carbonate resources. Previously, these carbonates have been investigated and found potentially suitable for use as aglime. However the aglime potential of many of these carbonate deposits remains largely unknown.

APPENDIX B:1 SIMPLIFIED GEOLOGICAL SUCCESSION OF ZAMBIA (AFTER MONEY, 1986; BOSSE, 1996)

Lithostratigraphy	Description	Age
Kalahari Group		Late Tertiary to Recent
- Zambezi Formation	Sand, ferricrete, silcrete, calcrete and evaporite	
- Barotze Formation	Clastics (quartzites, sandstones and conglomerates) and carbonate	
Karoo Supergroup		Carboniferous to Lower Cretaceous
- Upper Karoo Group	Arkoses and basalts	
- Lower Karoo Group	Tillites, clastics (sandstones, mudstones and shale), coal and carbonates	
Lower Palaeozoic	Quartzites, shales and arkoses	Lower Palaeozoic
Katanga Supergroup		Upper Precambrian
- Upper Katanga	Sandstones, (dolomitic) shales, marbles, arkoses and quartzites	
- Middle Katanga	Shales, sandstones and conglomerates, plus dolomitic carbonates, ironstones and fluvioglacial deposits	
- Lower Katanga	Basal conglomerate, quartzite, arkoses and sandstone overlain by dolomitic carbonates and shales	
Basement Complex		Lower Precambrian
- Muva Supergroup	Basal conglomerates, metavolcanics, quartzites, sandstones, slates and phyllites	
- Lufubu	Migmatites, gneisses, ironstones, quartzites, marbles, amphibolites, metavolcanics, syenites and granites	

APPENDIX B:2 CARBONATE OCCURRENCES IN ZAMBIA

Lithostratigraphy	Local names	Lithology	Province (Geological map in brackets)
Kalahari Group			
Zambezi Formation	un-named	Calcrete	
Barotze Formation	un-named	Reddish- to yellowish-brown, medium grained, compact granular, silicified, lacustrine limestone	North-Western (West Lunga River area)
KAROO SUPERGROUP			
Lower Karoo Group			
Madumabisa Formation	un-named	Blue-grey, brown to green, fine-grained, massive, argillaceous limestone associated with mudstone & sandstone	Southern (Monze (Kawezi River),Chezya River & Masuku- Kabanga areas)
	un-named	Blue-grey to brown, fine, massive lacustrine limestone intercalated within Karoo sediments	Southern (Monze area; W of Monze)
KATANGA SUPERGROUP			
Kundelungu Group			
Upper Kundelungu Formation			
	Barangu Dolomite	Dolomitic marble	Copperbelt (Chingola & Luswishi Dome area)
	Luapula Beds (Matanda; Bukanda Kaniembe (Lojoy) & Kosamu limestones)	Hard, blue to pink, laminated or massive dolomitic marbles marbles interbedded with shales, sandstone & conglomerate (Used for the production of lime)	Luapula (W of Mansa area; Matanda, Bukanda, Kaniembe, Kosamu)
Kaosna Formation	Un-named	Buff, fine grained marble with abundant clasts of quartz, phyllite, sandstone & carbonate.	North-Western (Ntambu & West Lunga River areas)
Kanyidma Formation	Un-named	Grey, grey-green to pink, fine grained, compact, brittle argillaceous to pure calcitic marble	North-Western (West Lunga River area)
Lower Kundelungu Formation	Kakontwe limestone	Fine to coarse, white to blue-black dolomitic marbles Fine to coarse, blue-black, banded calcitic marbles (Calcitic marble used to produce lime & cement)	Copperbelt (Ndola & Bwana Mkubwa area; Quarries include : Ndola West, Foxcut, Mwateshi, Itawa & Maryland)

APPENDIX B:2 CARBONATE OCCURRENCES IN ZAMBIA continued

Lithostratigraphy	Local names	Lithology	Province (Geological map in brackets)
KATANGA SUPERGROUP			
Kundelungu Group			
	Carbonate Formation	Dolomitic marble (lower section) and calcitic marble (middle section)	North-Western, Central & Southern (Mapanza Mission (W of Monze); NW of Mumbwa)
	Un-named	Albitised dolomitic breccia	Copperbelt (Chingola area)
Nyama Formation	Muchinda limestone	White, grey, blue-grey to pink, fine grained, banded dolomitic marbles and white to grey, coarse grained, banded calcitic marbles. Calc-silicates also occur.	Central & Lusaka (Lukanga Swamp (Kembe River), Chisamba (SW of Kabwe), Chainama Hills (Muchinda River, NE of Lusaka) & Chipembi areas)
West Lunga Formation	Un-named	Grey, grey-green to white, fine to coarse grained banded calcitic marble. Grey, brown to purple-brown, fine to medium grained dolomitic marble. Dolomitic calcite & calcitic dolomite marbles also occur.	North-Western (Ntambu, West Lunga River & Kabompo Dome (Kamilambu stream) areas)
Undifferentiated Kundelungu	Kawena sandstone	Limestone bands in sandstone & siltstone	Central (Mwembeshi River area)
Middle Katanga			
Mwashia Formation	Broken Hill Series (Broken Hill Dolomite)	White, pink to brown, fine to coarse dolomitic marbles and grey, coarse, calcitic marbles	Central (Luri Hills (SE of Mumbwa) & Nansenga River areas)
	Un-named	Limestone bands in schists	Central
Mine Series Group			
Upper Roan Formation	Un-named	Extensive deposits of white, grey, brown to pink, fine grained, dolomitic marble	Copperbelt (Ndola, Luanshya, Bwana Mkubwa & Musofu River areas) (Mpongwe area : Chinwa stream; Kashinga - Kanyenda ; Mkubwe road; St. Anthony Mission; Kashiba Lake; Lake Nampamba, and E of Mpongwe Co.)
Lower Roan Formation	Un-named	Intercalations of impure dolomitic marbles	Copperbelt (Luanshya area)
	Un-named	Pale grey to pink, fine grained, banded dolomitic marble (which grades into silicified dolomitic marble) associated with shale & quartzite	Central (Mosofu River, Mkushi (NW of Mkushi) & Nansenga River areas)

APPENDIX B:2 CARBONATE OCCURRENCES IN ZAMBIA continued

Lithostratigraphy	Local names	Lithology	Province (Geological map in brackets)
KATANGA SUPERGROUP			
Broken Hill Group			
Lusaka Formation	Lusaka Dolomite	Pink, white to grey, fine to medium grained, massive to banded dolomitic marble, dolomitic limestone and grey banded calcitic marbles	Lusaka & Central (Mwembeshi River, Leopards Hill, Kafue & Lusaka areas)
Mampompo (Cheta) Formation	Mampompo Limestone	White to blue-grey, fine to coarse grained, banded dolomitic limestone & dolomitic marble. Occassional calcitic marbles. (Used for aggregate, building stone, road & agricultural lime, fillers and cement)	Lusaka, Central & Southern (Mazabuka, Mwembeshi River (50 km W of Lusaka), Chainama Hills, Leopards Hill (Marble Hill), Lusaka, Kafue (Shimbala Quarry, Chilanga Cement Ltd) & Monze areas)
Matero (Chunga) Formation	Luimba iimestone	Calcitic & dolomitic marbles hosted in calc-silicate rich dolomitic marbles	Lusaka (Leopards Hill & Lusaka areas (Chalimbana, E of Lusaka))
Monze Group			
Kaleya Formation	Kaleya Limestone	Impure, thinly bedded dolomitic marls	Southern & Lusaka (Mazabuka, Kafue, Magoye & Gwembe (NE of Monze) areas)
Muzuma Formation	Muzuma Formation	Marble intercalations in calc-silicates	Southern (Chikankata (E of Monze) & Magoye & Gwembe (NE of Monze) areas)
Chifumpu Formation	Chifumpu Limestone	Dolomitic & calcitic marble (occassionally silicified)	Lusaka & Southern (Kafue & Magoye & Gwembe (NE of Monze) areas)
Chafugoma (Wamikumbi) Formation	Mujimbeji Marble	Grey, grey-blue & white, medium to coarse grained banded calcitic marbles interbedded with brown fine grained dolomitic marbles within mica schist	North-Western (Ntambu, Kabompo Gorge, Kabompo Dome (Mujibeji & Kalaba Rivers), Solwezi & West Lunga River areas) (Solwezi district : Kapeshi school;Chombela; Solwezi South; Kansanshi; Jiwundu swamp; Kisasa school; Kabompo district : Ndondo; Manyinga; Zambezi district)
Chivuna Formation	Chivuna Limestone	Dolomitic marble	Southern (Magoye & Gwembe (NE of Monze) area)
Ngoma Formation	Un-named	White, pink, grey to blue, massive & banded calcitic & dolomitic marbles	Southern (Monze & Chikankata (Namaila - Lusengesi River) areas)

APPENDIX B:2 CARBONATE OCCURRENCES IN ZAMBIA continued

Lithostratigraphy	Local names	Lithology	Province (Geological map in brackets)
KATANGA SUPERGROUP **Monze Group cont/d**			
Nadongo Formation	Un-named	White, grey, brown to pink, medium to coarse grained impure & pure calcitic & dolomitic marbles	Southern (Magoye & Gwembe (NE of Monze) & Chikankata areas)
Katanga Undifferentiated			
	Un-named	Shaly limestone in pelitic schists	Central (Leopards Hill area)
	Muyuni shales	Thinly bedded pink, blue-grey to brown, medium to coarse grained dolomitic marbles & white calcitic marbles interbedded in Muyuni Shales	Lusaka & Central (Mwembeshi River (50 km W of Lusaka), Leopards Hill & Chainama Hills (Chalimbana) areas)
Mvuvye Group	Mvuvye Marble	White, grey,bluish-grey, yellowish-brown, brown to pink, fine to coarse-grained, hard & compact dolomitic marble. Calc-silicates also occur.	Eastern (Mwanjawantu & Petauke (Mvuvye & Kanyena Rivers) & Nyimba (SE of Hofmeyer Mission; SE, S & around Nyimba town) areas)
	Chipongwe psammite	Limestone & dolomite bands	Lusaka (Kafue area)
Mazabuka Group	Un-named	Limestone & dolomite	Lusaka (Kafue area)
Mapanza Carbonate Formation	Un-named	White, grey to cream, medium to coarse grained, hard to compact, banded calcitic marble. Varieties include : brown, micaceous & friable marble; & grey banded marble. Occassional copper staining. Calc-silicates also occur	Southern (Monze & Mapanza Mission (WNW of Macha Mission) areas)
Upper Chilumbwe Formation	Chilumbwe schist	White to grey, fine to coarse grained calcitic marble Locally white to pink, fine to coarse dolomitic marble	Southern (Choma & Mapanza Mission (Chitambo; Monze) areas)
	Un-named (Masangu Limestone)	Limestone horizon (White, coarse grained, massive, sugary texture)	Southern (Chikankata area (Masangu Farm, SE of Mazabuka))
Kangomba Formation	Un-named	Banded dolomitic marble	Central (Chisamba area)

APPENDIX B:2 CARBONATE OCCURRENCES IN ZAMBIA continued

Lithostratigraphy	Local names	Lithology	Province (Geological map in brackets)
MUVA SUPERGROUP			
Manshya Group	Mpangala Marble	Foliated, recrystallised carbonate	Northern (Isoka & Mulilansolo Mission area)
Mpanshya Group	Un-named	Thin bands of pure dolomitic marbles & impure calc-silicate marbles	Eastern & Central (Nyimba & Luano Valley areas)
Sasare Group	Un-named	White, buff, grey, green to blue, banded impure dolomitic marble & calc-silicate rocks (previously used for lime production)	Eastern (Sasare (Chinkombe; W of Msoro Mission) area)
Fombwe Group		Lenses of white coarse-grained calcitic marble within granulite (previously used for lime production)	Eastern (Sasare area)
Lusandwa Group		White, coarse grained dolomitic & calcitic marble bands in Chindeni & Msoro Gneisses. Calc-silicates also occur.	Eastern (Lusandwa River area; quarries near Ukwimi & Msoro Mission)
Kafue Group			
Mulola Formation	Un-named	Limestone & dolomite bands	Lusaka (Kafue area)
Undifferentiated Muva	Un-named	Marble	Lusaka & Central (Rufunsa - Lukusashi area)
BASEMENT COMPLEX			
	Un-named	Dolomitic limestone	Lusaka (Lusaka area)
	Un-named	Grey, coarsely crystalline calcitic marble	Eastern (Machinje Hills area)
	Un-named	Marble (Hardrock aggregate quarry)	Eastern (South of Lundazi)
	Un-named	Marble (Ground & used as aglime)	Central (Muchinga, East of Serenje)
	Un-named	Marble, with occassional banding	Southern (Masuku-Kabanga area)
Mpande Formation	Un-named	Pink, grey to white, fine to coarse grained, calcitic to dolomitic marbles	Southern (Chikankata; NW of Simwambwa)

APPENDIX B:2. CARBONATE OCCURRENCES IN ZAMBIA continued

Lithostratigraphy	Local names	Lithology	Province (Geological map in brackets)
MISCELLANEOUS			
Carbonatite	Nkombwa Hill	Dolomitic carbonatite, silicified carbonatite, carbonatite & pure ankeritic carbonatite. Dolomitic carbonatite is white, grey to brown, banded to massive with veins of ankeritic carbonatite. It is mainly coarse grained, with some fine-grained & pegmatitic zones.	Northern (Isoka area; occurs as inselberg 25 km E of Isoka)
	Un-named	Carbonatite	Lusaka (Kafue area)
	Kaluwe	Homogeneous carbonatite & carbonatite agglomerates	Eastern (200 km E of Lusaka)
	Chasweta	Grey, brown to pink, medium grained carbonatites (locally silicified)	Eastern (200 km E of Lusaka)
Travertine	Un-named	Travertine overlying marbles	Eastern (NW of Luangwa)

APPENDIX B:3 SOURCES OF INFORMATION

General sources

Only a cursory level of information on carbonate rocks in Zambia is available. The majority of data in Appendix B2 was derived from two sources, namely the maps and memoirs of the Geological Survey Department, and the agricultural lime reports of the former Mineral Exploration (Minex) Department of ZIMCO Ltd. However information was also obtained from the reports and records of a number of other organisations including the University of Zambia (UNZA), UNDP (United Nations Development Programme) / UNIDO (United Nations Industrial Development Organisation), Norwegian Agency for International Development (NORAD), Southern African Development Community (SADC), and the Federal Institute for Geosciences and Natural Resources (BGR), Germany.

ZIMCO Minex reports

A number of investigations of the agricultural lime potential of Zambian carbonate rocks were carried out by Minex, an organisation which has been incorporated into the Geological Survey Department. These investigations typically included a brief locality description, lithological details, a technical evaluation and reserve estimations. Information on access, availability of power and water and the prevailing climate are also occasionally given. The technical evaluation includes chemical analyses (% Ca, Mg, Fe & Mn). Neutralization values (NV) were expressed as % calcium carbonate equivalent (CCE).

Zambian Government

Detailed pre-feasibility reports on the production of agricultural lime in Solwezi, North-western province and in Northern Province were prepared by UNDP/UNIDO for the Zambian Government Ministry of Commerce, Industry & Foreign Trade in 1981. These reports identified likely sources of agricultural lime, local consumers (and appropriate application rates) and outline the capital equipment requirements and costs for a 35 tonne per day agricultural lime production plant (UNDP/UNIDO 1981a & b).

The UN Department of Technical Cooperation for Development commissioned a fundamental review of the lime industry in the SADC region in 1990 in collaboration with the SADC Mining Sector Coordinating Unit. The review was carried out by Austrian consultants (AUSTROPLAN, 1990). The current and future production and consumption of lime was examined. The availability of carbonate resources and the use of appropriate “small-scale” methods for lime production were also discussed. Priorities were identified for each country in the region. In Zambia, it was concluded that the supply of agricultural lime and ground limestone is inadequate. It was therefore recommended that future investigations should focus upon the small-scale production of agricultural lime and ground limestone.

NORAD

A comprehensive review of agricultural liming in Zambia was produced as part of the work arising from the Soil Productivity Research Programme in the High Rainfall Areas of Zambia conducted by the Agricultural University of Norway and the NORAD (Oygard, 1987). This report describes the causes and consequences of soil acidity, the costs and benefits of liming, the current supply and demand of aglime in Zambia and possible future production sites. The proposed aglime production plant at Chivuna, Southern Province is also described.

University of Zambia

Researchers from the University of Zambia (UNZA) presented a paper on the potential use of carbonate rocks for agriculture in Zambia at the International Conference on Industrial Minerals held in Lusaka in 1995. This paper succinctly summarizes the main dilemma of agricultural use and production particularly highlighting the lack of awareness of the need for agricultural lime use and the issue of high transportation costs. (Shitumbanuma & Simukanga, 1995).

Reviews

A review of the geology of Zambia was published by Money in 1986. A country-by-country review of the limestone and dolomite resources of Africa was published in 1996 by Geologisches Jahrbuch Reihed (Bosse, 1996). This summarises much of the information on carbonates contained in the reports accompanying the 1:100,000 geological maps produced by the Geological Survey Department.

APPENDIX B:4
POTENTIAL AGRICULTURAL LIME SITES

Potential localities for field work as part of ODA TDR project 'Local development of affordable lime in Southern Africa".

1. NORTH-WESTERN PROVINCE

1.1. West Lunga Formation, Kundelungu Group, Katanga
Banded grey to white calcitic marble and grey to brown dolomitic marble

Ntambu, West Lunga River & Kabompo Dome areas

1.2. Chafugoma (Wamikumbi) Formation, Monze Group, Katanga
Banded grey & white calcitic marble interlayered with brown fine grained dolomitic marble

1.2.1. Solwezi District
Kapeshi school calcitic & dolomitic marble
Chombela calcitic & dolomitic marble
Solwezi south dolomitic marble
Kansanshi calcitic & dolomitic marble
Jiwundu Swamps calcitic & dolomitic marbles
Kisasa school dolomitic marble

1.2.2. Kabompo District
Ndondo dolomitic calcrete, breccia and marble
Manyinga (Kabompo district) dolomitic limestone

1.2.3. Zambezi District
Lunkunyi (Zambezi district) calcrete, calcitic & dolomitic marbles

2. COPPERBELT PROVINCE

2.1. Barangu Dolomite, Upper Kundelungu Formation, Kundelungu Group, Katanga
Dolomitic marble

Chingola & Luswishi Dome areas

2.2. Kakontwe Limestone, Lower Kundelungu Formation, Kundelungu Group, Katanga
White to black dolomitic marble and banded blue-black calcitic marbles

Ndola & Bwana Mkubwa areas including the following quarries:
Ndola West, Foxcut (Ndola Lime Ltd & Chilanga Cement Ltd), Mwateshi, Itawa & Maryland.

APPENDIX B:4
POTENTIAL AGRICULTURAL LIME SITES continued

2.3. Upper Roan Formation, Mine Series Group, Katanga
White to pink fine grained dolomitic marble

Ndola, Luanshya, Bwana Mkubwa, Musofu River & Mpongwe areas
Mpongwe area includes deposits of dolomitic and calcitic limestone at:
Chinwa stream; Kashinga village; Mkubwe road; St. Antony's Mission; Kashiba Lake; Lake Nampamba; and, Mpongwe Co.

3. LUAPULA PROVINCE

3.1. Luapula Beds, Upper Kundelungu Formation, Kundelungu Group, Katanga
Massive blue to pink dolomitic marbles

Mansa (W of Mansa including Matanda; Bukanda; Kaniembe; Kosamu) area

4. WESTERN PROVINCE

No reported carbonates

5. CENTRAL & LUSAKA PROVINCES

5.1. Muchinda Limestone, Nyama Formation, Kundelungu Group, Katanga
Banded white to grey, fine grained dolomiitic and calcitic marbles

Lukanga Swamp (Kembe River), Chisamba (SW of Kabwe), Chipembi and Chainama Hill (Muchinda River, NE of Lusaka) areas

5.2. Broken Hill dolomite, Mwashia Formation, Katanga
White to brown dolomitic and calcitic marbles

Luri Hills (SE of Mumbwa) & Nansenga River areas

5.3. Lower Roan Formation, Mine Series Group, Katanga
Banded grey to pink fine grained dolomitic marble

Mosofu River, Mkushi (NW of Mkushi) and Nansenga River areas

5.4. Lusaka Dolomite, Lusaka Formation, Broken Hill Group, Katanga Banded pink to grey dolomitic and calcitic marbles

Mwembeshi River, Leopards Hill, Kafue & Lusaka areas

APPENDIX B:4
POTENTIAL AGRICULTURAL LIME SITES continued

5.5. Mampompo Limestone, Mampompo (Cheta) Formation, Broken Hill Group, Katanga
Banded white to grey dolomitic and calcitic limestones & marbles

Mwembeshi River (50km W of Lusaka), Chainama Hills, Leopards Hill (Marble Hill), Lusaka and Kafue (Shimbala Quarry, Chilanga Cement Ltd) areas

5.6. Luimba Limestone. Matero (Chunga) Formation, Broken Hill Group, Katanga
Calcitic and dolomitic marbles
Leopards Hill and Lusaka (Chalimbana, E of Lusaka) areas

6. SOUTHERN PROVINCE

6.1. Mampompo Limestone, Mampompo (Cheta) Formation, Broken Hill Group, Katanga
Banded white to grey dolomitic and calcitic limestones & marbles

Mazabuka area

6.2. Kaleya Limestone, Kaleya Formation, Monze Group, Katanga
Impure, thinly bedded dolomitic marls

Mazabuka, Kafue, Magoye & Gwembe (NE of Monze) areas

6.3. Chifumpu Limestone, Chifumpu Formation, Monze Group, Katanga
Dolomitic and calcitic marbles

Kafue, and Magoye & Gwembe (NE of Monze) areas

6.4. Chivuna Limestone, Chivuna Formation, Monze Group, Katanga
White coarse grained dolomitic limestone

Magoye & Gwembe (NE of Monze) area

6.5. Ngoma Formation, Monze Group, Katanga
Banded white to grey calcitic and dolomitic marbles

Monze and Chikankata (Namaila-Lusengesi River) area

6.6. Nadongo Formation, Monze Group, Katanga
White to grey calcitic and dolomitic marbles

Magoye & Gwembe (NE of Monze) areas

APPENDIX B:4
POTENTIAL AGRICULTURAL LIME SITES continued

6.7. Mapanza Carbonate Formation, Undifferentiated Katanga
Banded white to grey calcitic marble

Monze & Mapanza Mission (the latter including deposits of calcitic limestone at: Mapanza; Chikwayi; Muyeke-Macha; Hanjabu; &, Dundwa.

6.8. Masangu Limestone, Undifferentiated Katanga
Massive, white coarse grained dolomitic marble

Chikankata (Masangu Farm, SE of Mazabuka) area

7. EASTERN PROVINCE

7.1. Mvuvye Marble, Mvuvye Group, Undifferentiated Katanga
White to brown dolomitic marble

Mwanjawantu, Petauke (Mvuvye & Kanyena Rivers) and Nyimba (SE of Hofmeyer Mission; SE, S & around Nyimba town) areas

7.2. Sasare Group, Muva
Banded white to grey dolomitic marble

Sasare (Chinkombe; W of Msoro Mission) area

7.3. Lusandwa Group, Muva
White coarse grained dolomitic & calcitic marble bands in gneiss

Lusandwa River (quarries near Ukwimi & Msoro Mission) area

7.4. Lithostrat ?
Lundazi marble

7.5. Carbonatite
Kaluwe & Chasweta (both 200 km E of Lusaka)

8. NORTHERN PROVINCE

8.1. Mpangala Marble, Manshya Group, Muva
Foliated, recrystalised carbonate

Isoka and Mulilansolo Mission areas

8.2. Carbonatite
Banded white to brown coarse grained dolomitic carbonatite

Isoka (Nkombwa Hill) area

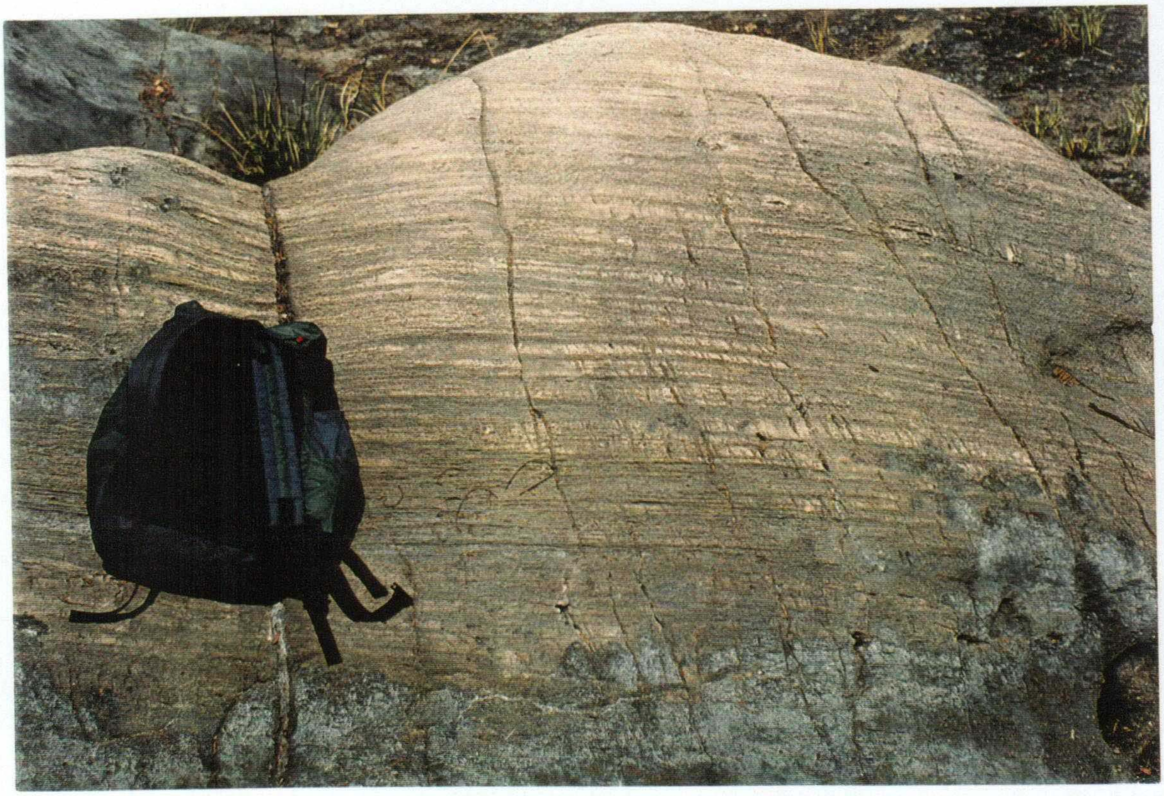

Plate B1. Outcrop of Mujimbeji Marble, Chombela, North-western Province

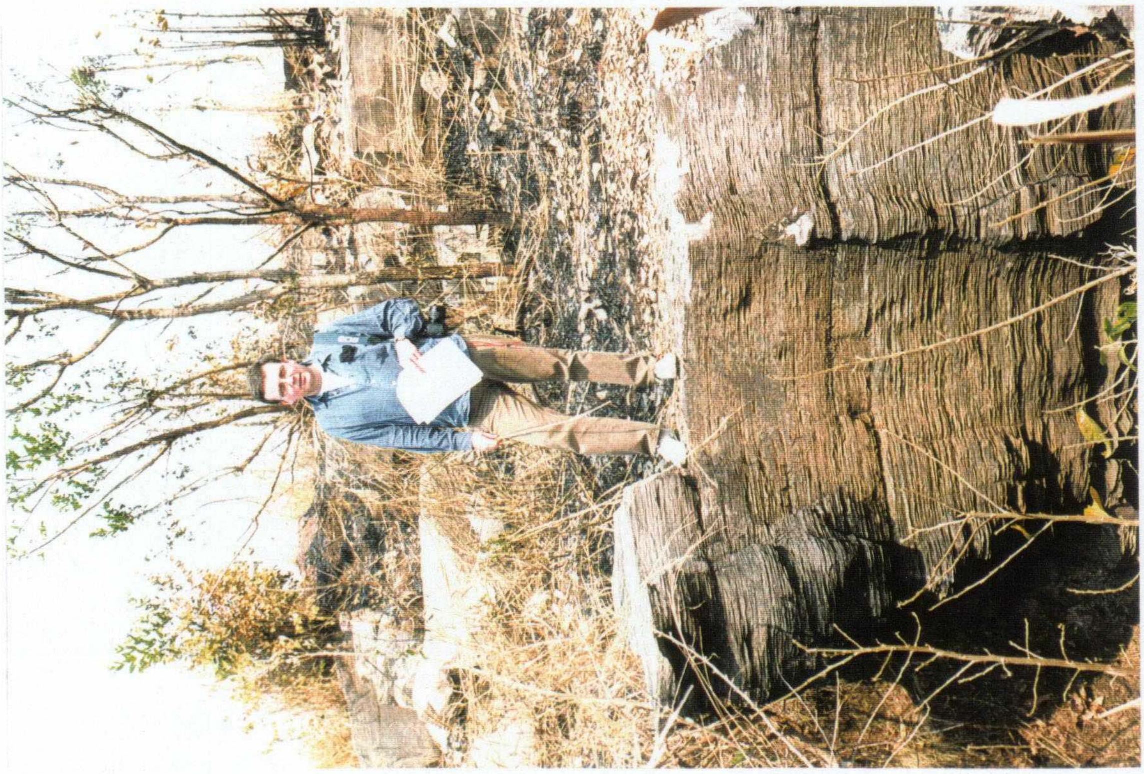

Plate B2. Outcrop of Luapula Beds, Matanda, Luapula Province

Plate B3. Outcrop of Lower Roan Formation, north of Mkushi, Central Province

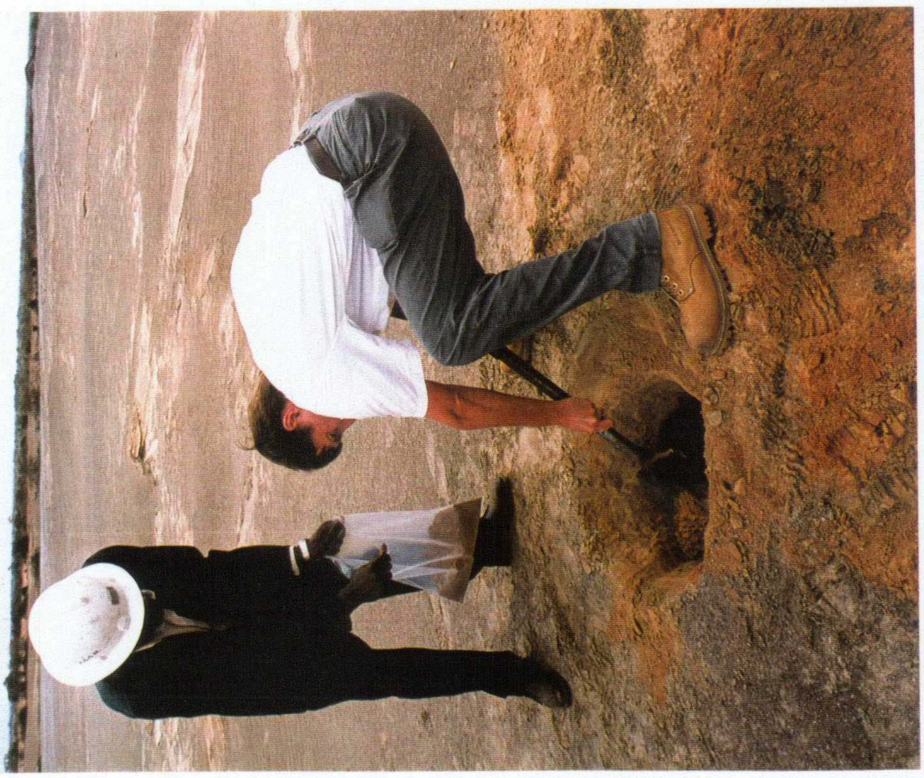

Plate B4. Tailings from Nampundwe Pyrite Mine Ltd, west of Lusaka

SECTION C:
LABORATORY ANALYSIS OF LIMESTONE AND DOLOMITE FOR USE AS AGRICULTURAL LIME

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1. INTRODUCTION

In this report, the properties of limestone and dolomite relevant to their use as agricultural lime (aglime) are discussed in the context of specifications and agronomic practice in the United Kingdom and United States. The overall objective of the report is to provide a set of appropriate laboratory methods for testing aglime for adoption by the Zambian Geological Survey Department. The individual aims of the report are to:

(1) Review the technical and scientific literature on the testing and analysis of aglime (see Appendix C1);
(2) Carry out a laboratory trial of the test methods identified to ensure their operation is satisfactory (see following section);
(3) Provide a step-by-step procedure for each of the laboratory methods recommended (see Appendix C2).

2. AGRICULTURAL LIME TEST METHODS AND LABORATORY TRIALS

2.1. Methods and samples

From the review of scientific and technical literature on aglime (Appendix C1), five properties of limestone and dolomite have been identified as being particularly pertinent to their use as aglime:

(1) Neutralization ability. Calcium carbonate equivalent (CCE) (ASTM C25-95).
(2) Plant nutrient content. Measurement of CaO and MgO (ASTM C25-95).
(3) Ease of pulverization. Grindability index (ASTM C110-95).
(4) Fineness. Dry sieve analysis on 8 mesh and 60 mesh (ASTM C602-95).
(4) Agronomic effectiveness. Reactivity by the method of Bornman et al. (1988).

Methods of the American Society for Testing and Materials have been selected as these generally contain more detailed procedures and notes than the equivalent methods of the British Standards Institution. The method of Bornman et al. (1988) has been selected for measurement of reactivity as only inexpensive laboratory glassware is used in this procedure ("pH stat" reactivity methods require an expensive automated titration assembly). This procedure is also an appropriate method for the Southern Africa region, having been developed in South Africa and tested on a large number of local aglime samples. Also, results obtained from the method can be related to both "pH stat" measurements of reactivity and particle-size (% <60 mesh).

One of the objectives of this project is to establish a laboratory within the Zambian Geological Survey Department (GSD), Lusaka, for testing limestone and dolomite for use as aglime. Prior to establishing this facility, a laboratory trial was carried out at BGS laboratories in the United Kingdom on each of the five methods listed above. The aims of the laboratory trial was to "shakedown" the methods and ensure they were operating satisfactorily, obtain information on the precision of these methods, and gather reference data for the Zambian laboratory. The procedures used in the laboratory trial are included in Appendices C2 - C6. 11 limestone and dolomite samples from Zambia, and two BGS in-house standards, were analyzed as part of the laboratory trial (Table C1).

Table C1. List of samples analyzed for the BGS laboratory trial.

Sample number	Locality	Zambian map sheet	Grid reference	Sample type
Field samples				
1	Chivuna	1627 B2 (1:50K)	NN 855 120	Dolomitic limestone
2	Masangu	1628 A1 (1:50K)	PN 116 299	Limestone
3	Ndola quarry, footwall	1:250K	0685 8574	Dolomitic limestone
4	Ndola quarry, hanging wall	1:250K	0685 8574	Limestone
5a	Solwezi south	1226 A2 (1:50K)	MS 359 524	Dolomitic limestone
5b	Solwezi south	1226 A2 (1:50K)	MS 359 524	Dolomitic limestone
6	Combela south	1226 B3 (1:50K)	MS 359 524	Dolomitic limestone
Ndola crushing plant samples				
CJM 287	Ndola aglime	1:250K	0685 8574	Limestone
CJM 290	Feed for lime kiln(s)	1:250K	0685 8574	Limestone
Agricultural lime samples				
CJM 288	Ndola, "farm 1" sample	1:250K	0780 8555	Agricultural lime
CJM 289	Ndola, "farm 2" sample	1:250K	0679 8852	Agricultural lime
BGS in-house standards				
L376	Bee Low Limestone, Derbyshire, England			Limestone
D428	Durness Limestone, Ullapool, Scotland			Dolomite

2.2. Results

The results of the laboratory trials are summarised in Table C2 and are given in full, along with the relevant test method, in Appendices C2 - C6. Particle-size analysis was not carried out, as particle size is a function of the amount of energy applied during grinding.

Table C2. Results of the test work on limestone & dolomite samples from Zambia

Sample	**Neutralisation Value** % CCE	**MgO** Wt %	**CaO** Wt %	**Grindability** Wt % <75 μm	**Reactivity** %
1	106	25.39	31.30	64.0	65.9
2	97	0.68	53.88	67.2	86.8
3	99	3.20	51.57	84.2	89.3
4	99	1.48	53.32	78.6	91.6
5a	107	23.67	30.52	37.3	63.8
5b	nd	23.61	30.42	44.8	77.0
6	107	23.67	32.28	51.3	71.7
CJM 287	98	0.61	54.75	93.6	77.3
CJM 288	97	0.36	54.21	nd	62.4
CJM 289	98	0.37	55.02	nd	63.8
CJM 290	96	0.30	53.78	nd	99.7
L376	99	0.31	55.27	nd	nd
D428	104	22.98	29.77	nd	nd

NB CCE = Calcium Carbonate Equivalent; nd = not determined

Calcium carbonate equivalent (CCE) results are listed in Appendix C2. Dolomites (1, 5 & 6) have the highest neutralization ability. For four duplicate CCE tests, an average coefficient of variation of 0.2% was obtained.

EDTA titration determinations of CaO and MgO are listed in Appendix C3. For comparison purposes, reference measurements of CaO and MgO obtained by major-element X-ray fluorescence (XRF) analysis are also included. There is a good correspondence between EDTA and XRF determinations (correlation coefficients of between 0.99-1.00), although the EDTA method underestimates the MgO and overestimates the CaO relative to the XRF measurements.

Appendix C5 lists grindability index results. Generally this shows that, limestones (grindability index = 67-94%) are easier to pulverize than dolomites (grindability index = 37-64%). Grindability may also be influenced by crystal size, as it is evident that the finer-grained limestone samples (3, 4 & CJM 290) also exhibit the highest grindability indices. Rocks consisting of small crystals have more natural fracture surfaces along which they are able to cleave, and therefore are able to be broken-down with less mechanical effort than a rock composed of coarse crystals. For five duplicate grindability tests carried out on samples 5 and CJM290, a coefficient of variation of between 1.8-8.6% was obtained.

Reactivity tests were carried out on the ground products obtained from the grindability index test. To some extent, the grindability test mimics industrial-scale grinding and the particle-size of the products obtained reflect the intrinsic softness/hardness of the parent rock. Prior to the reactivity test, a sub-sample was dry-screened on 8 mesh (2.36 mm) and 60 mesh (0.25 mm) and a fineness factor calculated. Reactivity results, as measured by the "resin suspension" method (Bornman et al., 1988), are listed in Appendix C6. Fineness factor and grindability index data are also included in Appendix C6 for comparison. For three duplicate reactivity tests, an average coefficient of variation of 9.5% was obtained.

Percentage reactivity is plotted against grindability index in Figure C1. Generally, softer limestone samples (square symbols) are more reactive than harder dolomite samples (circular symbols). As a check of whether BGS results were consistent with reactivity data obtained by Bornman et al. (1988), Zambian results are also plotted on a chart of percentage reactivity versus percentage <60 mesh in Figure C2. On this chart, Zambian results plot along a similar diagonal trend as the South African data, suggesting that BGS reactivity determinations are satisfactory, although products obtained from the grindability index test are generally finer than commercial South African aglime.

3. CONCLUSIONS

3.1. Literature review

The key properties of limestone and dolomite used as aglime are:

(1) Neutralization ability (calcium carbonate equivalent) (CCE)
(2) Plant nutrient content (% CaO and % MgO)
(3) Ease of pulverization (grindability index)
(4) Fineness (particle-size)
(5) Effectiveness (reactivity)

3.2. BGS laboratory trial

Results of a preliminary trial of the five methods listed in Appendices C2 - C6 on 11 samples of limestone and dolomite revealed that:

(1) Calcium carbonate equivalent (CCE) by ASTM C25-95 is a simple, rapid, precise method for measurement of neutralization ability.
(2) There is a good correspondence between % CaO and % MgO estimated by EDTA titration (ASTM C25-95) and X-ray fluorescence (XRF) analyses of CaO and MgO content (correlation coefficients = 0.99-1.00).

(3) Generally, limestones (grindability index = 67-94%) are easier to pulverize than dolomites (grindability index = 37-64%). Crystal size of the parent rock also influenced grindability.
(4) Reactivity by the method of Bornman et al. (1988) correlates with fineness and inversely with dolomite content.

3.3. Rationale for laboratory testing

The five tests methods recommended in this report are suitable for the assessment of the aglime potential of limestone and dolomite deposits. They are also valuable procedures for fundamental characterization of aglime used in field and laboratory crop trials.

APPENDIX C1:
KEY PROPERTIES OF AGRICULTURAL LIME

Background

Scientific and technical literature on testing and analysis of agricultural lime (aglime) is reviewed below. To obtain relevant publications, Bath Information Data Services (BIDS) and GEOREF bibliographic databases were accessed and searched using a variety of keywords. The degree to which aglime ameliorates soil acidity and improves crop yield is usually termed "effectiveness." In this review, where possible, the technical properties of limestone and dolomite have been discussed in relation to effectiveness and practical agronomic issues.

Chemistry

The majority of aglime is derived from crushed limestone and dolomite. Aglime of this type essentially consists of the minerals calcite [CaCO3] and/or dolomite [Ca,Mg (CO3)2]. A simple mineralogical classification of limestone and dolomite is given in Table C3.

Table C3. A simple mineralogical classification of limestone and dolomite.

Classification	Calcite (%)	Dolomite (%)	Equivalent MgO (%)	Equivalent CaO (%)
Limestone	90-100	0-10	0-2.2	53.5-56.1
Dolomitic limestone	50-90	10-50	2.2-10.9	43.2-53.5
Calcitic dolomite	10-50	50-90	10.9-19.7	33.0-43.2
Dolomite	0-10	90-100	19.7-21.9	30.4-33.0

Both Ca and Mg are essential plant nutrients (Murphy & Follett, 1978) and their levels within limestone and dolomite used as aglime need to be quantified. Both the American Society for Testing and Materials (ASTM) and the British Standards Institution (BSI) publish an EDTA titration method for determining the CaO and MgO content of limestone and dolomite, ASTM C25-95 and BS 6463: Part 2, respectively. In the UK, dolomitic limestone sold as aglime (i.e. magnesian limestone, see Table 4) is required to contain >15% MgO. Tether & Money (1986) suggest that aglime should ideally contain >6% MgO.

Particle-size

Murphy & Follett (1978) identified two principal factors as controlling the effectiveness of aglime: (1) Particle-size; and (2) neutralization ability. Particle-size was defined in terms of fineness factor calculated as follows:

Fineness factor (%) = 0.5A + B

Where

A = weight percent between 8 mesh (2.36 mm) and 60 mesh (0.25 mm)
B = weight percent less than 60 mesh (0.25 mm)

In a review of US liming materials and practices, Barber (1984) suggests that aglime should have a fineness of 80% <8 mesh (2.36 mm). Also, from particle-size analysis of 193 aglimes from 33 US states it was found that 20-55% of material was <100 mesh (0.15 mm). Previous agronomic research in the US has related % <60 mesh (0.25 mm) (X) to the "effectiveness" of aglime expressed as the degree of dissolution within the soil after 3 months (Y). On the basis of tests carried out on 99 aglimes samples, Barber (1957) reported that:

$$Y = 0.77X + 26.7$$

[R2 = 0.96]

According to Barber (1984), the results of these agronomic experiments demonstrated that % <60 mesh of an aglime was an adequate measure of degree of fineness that correlated well with effectiveness.

Withers (1993) reviewed the influence of particle-size on the agronomic effectiveness of aglime, and also the significance of particle-size within the context of UK and EU fertilizer regulations. For crop experiments carried out under idealized laboratory conditions, the influence of degree of fineness on effectiveness has been demonstrated. However, under "real" field conditions, the effect of particle-size is probably less critical as other factors (non-uniform spreading, variable soil moisture etc.) are more significant. Withers suggested that a particle-size of between 20 mesh (0.85 mm) and 100 mesh (0.15 mm) is entirely adequate at raising soil pH over the time span of crop rotation. From crop trials carried out using aglime of this particle-size range, neither degree of fineness or composition (i.e. relative proportions of dolomite and calcite) appear to limit effectiveness. Withers argued that the particle-size spectrum specified for aglime by the UK Fertilizer Regulations Act 1992 (i.e. 40-50% <100 mesh) are beneficial in that they provide short, medium and long term control of soil acidity.

Withers made the following conclusions: (1) aglime particles > 20 mesh (0.85 mm) have comparatively little agronomic value; while (2) those of <60 mesh (0.25 mm) will completely dissolve on contact with soil within one year; and (3) those of <100 mesh (0.15 mm) react "very quickly" on contact with soil.

Withers also highlighted recent research on aglime which has attempted to identify a single method capable of measuring both neutralizing ability and particle-size. One example given is the measurement of reactivity by the method of Hartwig & Loeppert (1992) (see Section 2.5.).

A booklet produced by the UK Agricultural Lime Producers Council (ALPC) (Anon, 1995) states that fineness of grinding has a proven relationship with crop yield and indicates that for cohesive liming materials the proportion of material >0.6 mm considerably reduces effectiveness. However, the ALPC information indicates that fineness is less significant for materials such as chalk and burnt lime which break down naturally within the soil. A summary of the particle-size characteristics of agricultural lime used in USA & UK is given in Table C4.

Table C4. Summary of the particle-size characteristics of agricultural lime, based on United Kingdom and United States practice.

Percentage particle-size finer than:									
ASTM C602-95			**UK Fertilizer Regs. (1991)**			**Other**		**Technical literature**	
#	**mm**	**Wt %**	**#**	**mm**	**Wt %**	**#**	**mm**	**Barber (1984)**	**Withers (1993)**
				5	100				
				3	>90				
8	2.36	>80						80% ideal	
						20	0.85		No agronomic value above 20 mesh
60	0.25	>20							Dissolves within one year
			100	0.15	>15			20-55% typical	Reacts very quickly. 40-50% ideal.

The ASTM publish a standard specification for agricultural liming materials (ASTM C602-95). This specification includes a method for dry sieve analysis on 8 mesh (2.36 mm) and 60 mesh (0.25 mm) for measurement of the fineness of aglime. Moisture content is determined as part of this sieve analysis procedure. According to Barber (1984), aglime sold from the quarry is permitted to contain up to 10% moisture. The ASTM particle-size classification of agricultural liming materials is outlined in Table C5.

Table C5. ASTM C602-95 particle-size classification of agricultural liming materials.

Class designation	**Minimum % passing 8 mesh (2.36 mm)**	**Minimum % passing 60 mesh (0.25 mm)**
S	100	100
T	99	75
O	95	55
N	90	40
E	80	25

Neutralization ability

Amelioration of soil acidity is the prime function of aglime. Overall nutrient availability and plant growth are typically maximized at near neutral pH. Addition of aglime improves availability of elements essential for plant growth, such as nitrogen, phosphorus and potassium, and simultaneously decreases availability of toxic elements such as aluminium and manganese. In practice, regulation of pH also needs take account the crop grown, land use and soil type. For example sugar beet growth is best under neutral to slightly alkaline conditions, while the growth of potatoes is favoured by a slightly acid environment.

In the US, neutralizing capacity of aglime is usually expressed in terms of the calcium carbonate equivalent (CCE), i.e. acid neutralizing ability expressed as the weight percent of calcium carbonate (%$CaCO3$). Pure limestone has a CCE of 100% whereas dolomite has a CCE of 108% due to the lower atomic mass of Mg relative to that of Ca. ASTM C25-95 includes a method for measuring CCE and ASTM C602-95 provides a chemical classification of agricultural liming materials on the basis of CCE values (Table C6).

Table C6. ASTM C602-95 chemical classification of agricultural liming materials.

Material	**Calcium carbonate equivalent (CCE) (%)**
Burnt lime	Not less than 140
Hydrated lime	Not less than 110
Limestone	Not less than 80
Slag	Not less than 80
Shells	Not less than 80

In contrast, in the UK, neutralizing ability is usually expressed as the percentage calcium oxide equivalent (% CaO) known as the neutralizing value (NV). NV is determined in the laboratory using a recognized British Standard procedure (BS 6463: Part 2: 1984). NV is quoted on an "as-received" and not a dry weight basis. Pure limestone has a NV of 56.0%. The BS NV for an aglime can be converted to an ASTM CCE value by multiplying by a factor of 100.088/56.079.

Reactivity

Reactivity is a kinetic parameter generally defined as the rate at which aglime will neutralize a soil. According to Barber (1984), the relative proportions of dolomite and calcite, degree of fineness and the physical properties of particles (e.g. softness and porosity) influence the reactivity of aglime.

Hartwig & Loeppert (1992) noted that much of the previous research on the reactivity of aglime involved dissolution in acidic reagents such as Na-oxalate, acetic acid, oxalic acid, hydrochloric acid, ammonium acetate and ethylenediaminetetraacetic acid (EDTA). However, a study by Van der watt & Croft (1993) found that such procedures (e.g. the method of Kjaer & Jensen, 1977) were insensitive and not capable of distinguishing differences in the reactivity of the several limestones tested.

Hartwig & Loeppert (1992) described a "pH stat" reactivity method based on the degree of dissolution of aglime relative to that of standard Iceland-Spar calcite (see also Moore et al., 1990). From pH stat results, values for CCE, surface area and effective particle-size distribution (see also Von Tress et al., 1985) were derived. Van der Watt & Croft (1993) described an alternative pH stat method in which 200 mg of aglime was digested in 250 ml of 0.1M HNO_3 using an automated titration assembly in which pH was maintained at a preset value of either 4.0, 4.5 or 5.0. For each pH stat experiment, % neutralization of the CCE was plotted with respect to time. For a given pH, a single kinetic parameter designated T1/2 was calculated, T1/2 being defined as the time in minutes required to neutralize 50% of the CCE of the sample. For a set of 15 limestone and dolomite samples, T1/2 values at pH 4.0 correlated with % <0.25 mm (correlation coefficient of 0.68), and also measurement of reactivity by the resin suspension method (correlation coefficient of –0.65). It was concluded that T1/2 at pH 4.0 was a valuable indicator of aglime reactivity.

Bornman et al. (1988) described the "resin suspension" method for determining reactivity which simulates the interaction between an aglime and soil in the laboratory. In this procedure, an ion-exchange resin is used to mimic an acid soil. 200 mg of aglime is added to 1 g of ion-exchange resin and 500 ml of dilute acetic acid. pH is then measured after a 24 hour period. Each batch of aglimes analyzed included a blank (i.e. no addition of aglime) and a control sample (200 mg of analytical grade $CaCO_3$). Percentage reactivity is then calculated as follows:

$$\text{Reactivity (\%)} = [(pHL - pH0) / (pHC - pH0)] \times 100$$

Where
pHL = pH of sample
pHC = pH of control
pH0 = pH of blank

Effective calcium carbonate (ECC) rating

Murphy & Follett (1978) suggest that the overall effectiveness of aglime can be calculated on the basis of an effective calcium carbonate (ECC) rating calculated from the product of the fineness factor multiplied by the CCE. An empirical relationship between ECC and effectiveness has been established on the basis of a large volume of data from crop trials. As stated previously the fineness factor used in the calculation of ECC is partly based on the amount of material passing 60 mesh, an indicator known to correlate well with degree of dissolution within the soil after 3 months.

Grindability

It is necessary to pulverize limestone and dolomite in order to obtain a suitable product for use as aglime. A laboratory method for the determination of limestone grindability using a ball mill is specified in ASTM C110-95 (1995). The grindability index obtained by this procedure is a signifier of the relative grindability or ease of pulverization of limestones and dolomites of different hardness. The ASTM method states that grindability index is useful, either for comparison purposes or acceptance testing, for those applications where finely-ground limestone is required.

UK regulations and specifications

The booklet published by the Agricultural Lime Producers Council (Anon, 1995) states that UK quarry-produced liming materials must comply with the Fertilizer Regulations (1991). UK Aglime is sold only under permitted names, each having a precise legal meaning and a set of specified characteristics know as "declarations." Generally, "neutralizing value (NV)" and the "amount passing a 150 μm (0.15 mm) sieve" are the two "declarations" specified, as outlined in Table C7 below.

Table C7. Names and definitions for UK quarry-produced materials sold as agricultural lime under the Fertilizer Regulations (1991).

Name	Largely composed of:	MgO (%)	<5 mm (%)	<3.55 mm (%)	<0.15 mm (%)
Ground limestone	$CaCO_3$	<15	100	>95	>40
Screened limestone	$CaCO_3$	<15	100	>95	>20
Limestone dust	$CaCO_3$	<15	100	>95	>20
Coarse screened limestone	$CaCO_3$	<15	100	>90	>15
Coarse limestone dust	$CaCO_3$	<15	100	>90	>15
Magnesian ground limestone	$CaCO_3$, $MgCO_3$	>15	100	>95	>40
Magnesian screened limestone	$CaCO_3$, $MgCO_3$	>15	100	>95	>20
Coarse screened magnesian limestone	$CaCO_3$, $MgCO_3$	>15	100	>90	>15
Coarse magnesian limestone dust	$CaCO_3$, $MgCO_3$	>15	100	>90	>15

Note: Names & definitions for chalk- and lime-based materials are specified but have not been listed here

Table C8. Physical and chemical properties of agricultural lime products sold by ARC Southern (ARC Ltd). Properties relating to the definition by law have been highlighted.

Fact Sheet	**SP6**	**SP7**	**SP8**	**SP9a**	**SP11**
Name					
Magnesian ground limestone	Yes				
Screened limestone		Yes	Yes	Yes	Yes
Chemical analysis (typical)					
CaCO3 (%)	54.00	94.00	97.00	96.00	98.00
MgCO3 (%	41.00	NS	0.91	0.76	NS
CaO (%)	30.00	NS	54.50	54.00	NS
MgO (%)	25.00	2.26	0.44	0.36	0.35
SiO2 (%)	3.00	0.80	1.30	0.89	0.30
S (%)	0.02	NS	0.04	0.20	NS
Al2O3 (%)	0.03	0.32	0.03	0.03	0.03
Fe2O3 (%)	3.20	0.15	0.12	1.19	0.03
LOI (%)	46.00	43.60	42.90	43.26	44.00
Neutralizing value (NV)	53-55	50-54	50-52	50-52	55.00
% Cumulative grading (typical)					
5.00 (mm)	100	100	100	100	100
3.35 (mm)	99	100	95	99	96
1.18 (mm)	90	76	65	86	67
0.300 (mm)	60	37	33	43	33
0.150 (mm))	40	28	22	30	23
0.075 (mm	35	19	15	24	18
Density (approximate)					
Compacted (Kg/m3)	1500		1450	1400	1500*
Loose (Kg/m3)	1300		1250	1200	NS

NS: Not specified

* Condition (i.e. loose or compacted) not stated

Of the UK companies contacted, neither Redland Aggregates (Redland Agricultural Lime) or Omya Croxton+Garry (AgLime Ltd) produce detailed specification sheets for their aglime products. In contrast ARC Southern do produce data sheets giving typical chemical and physical properties of materials sold. These are listed in Table C8 above.

APPENDIX C2:
RECOMMENDED METHODS FOR TESTING LIMESTONE AND DOLOMITE FOR AGRICULTURAL LIME USE

Method 1. Calcium carbonate equivalent (CCE) (after ASTM C25-95)

Reagents
1 litre 1.0N hydrochloric acid, prepared from concentrated ampoules
20g sodium hydroxide, analytical grade
10g phenolphatalein
100 ml ethanol, analytical grade

Apparatus

1 litre volumetric flask	100 ml pipette
Pipette filler	Plastic dropper
500 ml Erlenmeyer flask (x10)	50 ml burette
Weighing bottles (x10)	Burette clamp and stand
Drying oven, 110°C	Desiccator
Magnetic stirring plate	Magnetic followers (x4)
1 litre polyethylene bottle (+ siphon tube & soda lime guard tube)	

Preparation of 1.0N HCl solution
1. In accordance with the manufacturer's instructions, transfer HCl from concentrated ampoules to a 1 litre volumetric flask and dilute 1 litre.

Preparation of 0.5N NaOH solution
1. Dissolve 20.000 g ($\pm$ 0.001 g) of analytical-grade sodium hydroxide (NaOH) in 150 ml of carbon dioxide-free water.
2. Cool to room temperature, transfer to a 1 litre volumetric flask and dilute to 1 litre.
3. If possible, store solution in a polyethylene bottle with a siphon tube and soda lime guard tube to prevent absorption of carbon dioxide from air.

Preparation of phenolphthalein indicator
1. Dissolve 1 g of Phenolphthalein in 100 ml of analytical-grade ethanol.

Procedure
1. Transfer approximately 5 g of the dry sample from an air tight container to a 500 ml Erlenmeyer flask and record weight in g to 3 decimal places (W).
2. Add 110 ml (V1) of HCl 1.0N (N1) from a pipette. (Note: please see calculation below for further advice on volume of HCl addition.)
3. Boil gently for 5 minutes or until only an insoluble residue remains.
4. Add 2-3 drops of phenolphthalein indicator to the flask and add a magnetic follower.
5. Place the flask on a magnetic stirring plate and adjust so that contents are stirred gently.

6. Titrate the sample against 0.5N NaOH (N2) added from a burette. As the end-point is being approached, a change from a clear solution to a pink colouration is observed in the area at centre of the flask where the titer is added. The end-point is reached when sufficient titer is added to achieve a pervasive and persistent bright pink colouration.
7. At the end-point, record the amount of NaOH titer added from the burette to the nearest 0.05 ml (V2).

Calculation

The CCE (%CaCO3) is calculated as follows:

CCE (%CaCO3) = [5.0045 (V1 N1 - V2 N2)] /W

Where

V1 = Volume of HCl solution used*
N1 = Normality of HCl solution = 1N
V2 = Volume of NaOH titer at the end-point in ml
N2 = Normality of NaOH solution = 0.5N
W = Sample weight in (g) recorded to three decimal places

Note

*V1 = 110 ml for dolomites or unknown samples
= 100 ml for limestone samples

The results of the laboratory trials using Zambian limestone and dolomite samples are given in Table C9.

Table C9. Calcium carbonate equivalent (CCE).

Collector No.	Locality	Sample type	Test 1	Test 2	Test 3	Test 4	Average	SD	Coefficient of variation
CJM 280	Chivuna	Dolomite	105.7	105.7	105.8	105.9	105.8	0.10	0.09
CJM 281	Matanda	Limestone	97.2	97.2	97.3	97.3	97.3	0.06	0.06
CJM 282	Ndola limestone foot wall	Dolomitic limestone	98.8	98.8	98.7	98.6	98.7	0.10	0.10
CJM 283	Ndola limestone hanging wall	Limestone	99.2	98.5	98.1	99.1	98.7	0.52	0.53
CJM 284a	Solwezi south	Dolomite	106.7	107.0	105.4	107.5	106.7	0.90	0.84
CJM 284b	Solwezi south	Dolomite							
CJM 285	Chombela south	Dolomite	106.4	106.5	106.4	106.5	106.5	0.06	0.05
CJM 287	Ndola limestone dust	Limestone	98.1	98.2	98.1	98.1	98.1	0.05	0.05
CJM 288	Ndola aglime lime (farm 1)	Agricultural lime	96.6	96.5	96.4	96.9	96.6	0.22	0.22
CJM 289	Ndola aglime lime (farm 2)	Agricultural lime	97.9	98.1	98.1	98.1	98.1	0.10	0.10
CJM 290	Ndola limestone feed	Limestone	95.9	96.0	96.0	96.0	96.0	0.05	0.05
L376	In-house BGS limestone standard	Limestone	99.0	98.9	98.7	98.7	98.8	0.15	0.15
D428	In-house BGS dolomite standard	Dolomite	104.1	103.9	104.0	104.1	104.0	0.10	0.09
Average									0.19

APPENDIX C3:
RECOMMENDED METHODS FOR TESTING LIMESTONE AND DOLOMITE FOR AGRICULTURAL LIME USE

Method 2. CaO and MgO by EDTA titration (after ASTM C25-95)

Reagents
100 g EDTA disodium dihydrogen, analytical grade
500 g potassium hydroxide, analytical grade
100 g ammonium chloride, analytical grade
1 litre 33% Ammonia solution (SG = 1.18)
500 g hydroxy naphthol blue indicator
10 g Calmagite
2 litres conc. hydrochloric acid
500 ml triethanolamine
100 g calcium carbonate, analytical grade
100 g magnesium carbonate, analytical grade

Apparatus
Magnetic stirring plate
Magnetic follower
pH meter and pH calibration buffer solutions
Hotplate
1 litre volumetric flask (x5)
1 litre plastic bottles for chemicals (x3)
10 ml pipette
20 ml pipette
50 ml burette
Burette stand and clamp
100 ml measuring cylinder
10 ml measuring cylinder
25 ml measuring cylinder
Funnels (x3)
500 ml Erlenmeyer flask (x2)
250 ml volumetric flasks (x2)
250 ml beakers (x10)
300 ml screw top bottles (x10)

Preparation of 0.4% EDTA solution
1. Dissolve 4.00 g of disodium dihydrogen EDTA in distilled water, transfer to a volumetric flask and dilute to 1 litre.

Preparation of standard KOH solution
1. Dissolve 56.00 g of potassium hydroxide in distilled water, transfer to a volumetric flask and dilute to 1 litre.

Preparation of ammonia buffer solution (pH 10.5)
1. Dissolve 67.50 g of ammonium chloride in 300 ml of distilled water, add 570 ml of 33% ammonia solution and dilute to 1L in a volumetric flask

Preparation of 10% HCl
1. Add 100 ml of conc. HCl to 900 ml of distilled water.
Preparation of 50% HCl

Hydrochloric 50% HCl
1. Add 500 ml of conc. HCl to 500 ml of distilled water.

Preparation of 33% triethanolamine
1. Add 250 ml of conc. triethanolamine to 500 ml of distilled water

Preparation of CaO standard solution (1 mg/ml)
1. Weigh 1.785 g of analytical grade CaCO3 into a 250 ml beaker and add 100 ml of 10% HCl.
2. Place on hot plate and heat gently until all CaCO3 has dissolved. Allow solution to cool to room temperature.
3. Transfer to a volumetric flask and dilute to 1 litre.

Preparation of MgO standard solution (1 mg/ml)
1. Weigh 0.063 g of Mg metal turnings (or 2.0919g of analytical grade MgCO3) into a 250 ml beaker and add 100 ml of 10% HCl.
2. Place on hot plate and heat gently until all metal has dissolved
3. Transfer to a volumetric flask and dilute to 1 litre.

CaO standardization

Note: CaO standardization is carried out on each new batch of EDTA solution prepared.

1. Pipette 10 ml of the CaO standard solution into a 500 ml Erlenmeyer flask and add 100 ml of distilled water
2. Place the flask on the magnetic stirrer and add approximately 10 ml of 0.4% EDTA solution to prevent precipitation of calcium.
3. Calibrate pH meter for the alkaline pH range.
4. Immerse pH electrode and adjust the pH of the solution to between 12-12.5 by addition of the standard KOH solution (Note: addition of around 2 ml of KOH was found to be sufficient, whereas the ASTM procedure indicates an addition of circa 15 ml KOH is necessary. Add KOH stepwise drop-by-drop.)
5. Add 0.4 - 0.7 g of hydroxy naphthol blue as an indicator. (Note: the 0.2-0.3 g of indicator recommended by the ASTM procedure imparted insufficient colour.)
6. Titrate against 0.4% EDTA solution until a clear blue end-point is obtained.
7. At the end-point, record the amount of 0.4% EDTA titer solution added (including the 10 ml added initially) to the nearest 0.05 ml.

8. Carry out two replicate analyses. Average the EDTA end-point value obtained from the three separate determinations.
9. Calculate the concentration of CaO in standard solution as follows:
CaO in standard solution (mg/ml)
= 10 mg CaO / average EDTA end-point

MgO standardization

Note: MgO standardization is carried out on each new batch of EDTA solution prepared.

1. Pipette 10 ml of the MgO standard solution into a 500 ml Erlenmeyer flask and add 100 ml of distilled water
2. Place the flask on the magnetic stirrer and add approximately 10 ml of 0.4% EDTA solution to prevent precipitation of calcium.
3. Calibrate pH meter for the alkaline pH range.
4. Immerse pH electrode and adjust the pH of the solution to pH 10.0 with the ammonia buffer solution. (Note: addition of around 2 ml of ammonia buffer was found to be sufficient, whereas the ASTM procedure indicates an addition of circa 15 ml ammonia buffer is necessary. Add ammonia buffer stepwise drop-by-drop.)
5. Add one or two grains of Calmagite indicator. (Note: the colouration imparted by the 0.4 g addition of Calmagite specified by the ASTM method was found to be too opaque.)
6. Titrate against 0.4% EDTA solution. At the end-point a purple-to-deep blue colour change is observed.
7. At the end-point, record the amount of 0.4% EDTA titer solution added to the nearest 0.05 ml.
8. Carry out two replicate analyses. Average the EDTA end-point value obtained from the three separate determinations.
9. Calculate the concentration of MgO in standard solution as follows:
MgO in standard solution (mg/ml)
= 10 mg MgO / average EDTA end-point

Sample digestion
1. Weigh approximately 0.5 g of sample and record weight in g to three decimal places
2. Transfer to a 250 ml beaker and add 10 ml of 50% HCl and slowly evaporate to dryness on the hotplate
3. Dissolve residue obtained in 25 ml of 10% HCl.
4. Dilute to 100 ml with distilled water and gently warm on a hotplate for 15 minutes until digestion is complete, then allow to cool to room temperature.
5. Transfer to a 250 ml volumetric flask and dilute to the 250 ml mark, mixing thoroughly.
6. Transfer the solution to a 300 ml screw top bottle and label with sample code.

Determination of CaO
1. Pipette 20 ml aliquot of the sample solution into a 500 ml Erlenmeyer flask. Dilute to 250 ml with distilled water

2. Add a magnetic follower and place flask on magnetic stirring plate.
3. Calibrate pH meter for the alkaline pH range.
4. Immerse pH electrode and adjust the pH of the solution to between 12-12.5 by addition of the standard KOH solution. (Note: addition of around 2 ml of KOH was found to be sufficient, whereas the ASTM procedure indicates an addition of circa 15 ml KOH is necessary. Add KOH stepwise drop-by-drop.)
5. If the sample is suspected to contain significant Fe, Mn or heavy metals, add 10 ml of the 33% triethanolamine solution.
6. Add 0.4 - 0.7 g of hydroxy naphthol blue indicator. (Note: the 0.2-0.3 g of indicator recommended by the ASTM procedure imparted insufficient colour.)
7. Titrate against 0.4% EDTA solution until a clear blue end-point is obtained.
8. At the end-point, record the amount of 0.4% EDTA titer solution added (including the 10 ml added initially) to the nearest 0.05 ml.

Calculation of CaO content (%)
Calculate CaO content of sample (%) as follows:

CaO content of sample (%) =
CaO in standard solution (mg/ml) x EDTA end-point (ml) x 1.25 / sample wt. (g)

Determination of MgO

Note: in this titration, combined calcium and magnesium in solution is determined.

1. Pipette 20 ml aliquot of the sample solution into a 500 ml Erlenmeyer flask. Dilute to 250 ml with distilled water
2. Add a magnetic follower and place flask on magnetic stirring plate.
3. Calibrate pH meter for the alkaline pH range.
4. Immerse pH electrode and adjust the pH of the solution to pH 10.0 with the ammonia buffer solution. (Note: addition of around 2 ml of ammonia buffer was found to be sufficient, whereas the ASTM procedure indicates an addition of circa 15 ml ammonia buffer is necessary. Add ammonia buffer stepwise drop-by-drop.)
5. Add one or two grains of Calmagite indicator. (Note: the colouration imparted by the 0.4 g addition of Calmagite specified by the ASTM method was found to be too opaque.)
6. If the sample is suspected to contain significant Fe, Mn or heavy metals, add 10 ml of the 33% triethanolamine solution.
7. Initially, titrate a volume of EDTA solution equivalent to the end-point obtained in the CaO determination for that sample.
8. Continue to titrate against 0.4% EDTA solution. At the end-point a purple-to-deep blue colour change is observed.
9. At the end-point, record the total amount of 0.4% EDTA titer solution added to the nearest 0.05 ml (including the volume added initially in step 7).

Calculation of MgO content (%)
Calculate MgO content of sample (%) as follows:

Firstly
True EDTA MgO end-point (ml)
= EDTA end-point in MgO determination - EDTA end-point in CaO determination

Then
MgO content of sample (%) =
MgO in standard solution (mg/ml) x True EDTA end-point (ml) x 1.25 / sample wt. (g)

The results of the laboratory trial using Zambian limestone and dolomite samples are given in Table C10.

**Table C10. CaO and MgO content by EDTA titration.
Reference XRF determinations included for comparison**

Sample	Sample type	Test 1 CaO%	Test 2 CaO%	Test 1 MgO%	Test 2 MgO%	Average CaO%	XRF CaO%	Average MgO%	XRF MgO%
CJM 280	Dolomite	33.80	28.80	27.14	23.63	31.30	30.24	25.39	21.83
CJM 281	Limestone	54.77	53.00	0.37	0.99	53.88	55.14	0.68	0.22
CJM 282	Dolomitic limestone	52.40	50.73	3.05	3.35	51.57	51.84	3.20	3.47
CJM 283	Limestone	55.70	50.95	0.24	2.72	53.32	55.59	1.48	0.38
CJM 284A	Dolomite	31.27	29.77	23.90	23.44	30.52	30.93	23.67	21.87
CJM 284B	Dolomite	30.88	29.96	24.08	23.14	30.42	30.98	23.61	21.85
CJM 285	Dolomite	32.64	31.91	22.85	24.48	32.28	33.06	23.67	20.08
CJM 287	Limestone	55.52	53.98	0.61	0.61	54.75	55.47	0.61	0.46
CJM 288	Agricultural lime	55.29	53.14	ND	0.36	54.21	54.48	0.36	0.41
CJM 289	Agricultural lime	56.30	53.74	0.25	0.49	55.02	55.21	0.37	0.50
CJM 290	Limestone	55.04	52.51	0.00	0.61	53.78	53.72	0.30	0.73
L376	Limestone	56.10	54.45	0.37	0.25	55.27	54.36	0.31	0.30
D428	Dolomite	30.10	29.43	23.20	22.77	29.77	35.99	22.98	21.90
Correlation coefficient CaO =	0.99								
Correlation coefficient MgO=	1.00								

APPENDIX C4:
RECOMMENDED METHODS FOR TESTING LIMESTONE AND DOLOMITE FOR AGRICULTURAL LIME USE

Method 3. Grindability index (after ASTM C110-95)

Apparatus
Ball mill:
Rotating mill (US Stoneware No 753-RM rotating mill, or equivalent)
Ceramic mill jar (US Stoneware mill jar No 774-B-00, or equivalent)
14 cm (5.5 inch) diameter by 17.2 cm (6.75 inch) height
Cylindrical ceramic grinding elements (x7)
23 g individual weight approx.
21 mm (3/16 inch) by 21 mm dimensions
160 $\pm$ 1 g total weight of grinding elements

Jaw-crusher:
Bico-Braun "chipmunk" type crusher, or equivalent
Capable of breaking large rocks to <6.35 mm (0.25 inch)

US Standard 8 inch diameter sieves:
6 (3.35 mm), 20 (850 μm), 40 (425 μm) and 200 mesh (75 μm) aperture

Drying oven (110°C)
Riffle splitter, 12.7 mm (1/2 inch) diameter chute
Stopwatch

Reagents
Milling solution:
0.1% solution of an acrylate-based dispersant
e.g. Alcosperse 149*, Alco Chemical Corp, or equivalent

*Supplier:
Narlex LD31 (an equivalent acrylate dispersant)
National Starch and Chemicals Limited
Speciality Polymers Division
Bruanston, Daventry
Northamptonshire
NN11 7JL United Kingdom
Tel +44 1788 890248
Fax +44 1788 891489

Procedure
1. Pass approx. 500 g of material through a jaw-crusher able to crush rocks to <6.35 mm (0.25 inch).

2. Dry-sieve the jaw-crushed material on a 850 μm (20 mesh) and a 425 μm (40 mesh) sieve. Please refer to method 5 below for guidance on the correct sieving technique.
3. Weigh out 20 ±0.01 g of dried 20 by 40 mesh rock (W1).
4. Add 180 ml of milling solution to a clean empty mill jar. Add the seven grinding elements and transfer the weighed sample to the mill jar.
5. Place the mill jar on the rotating mill and operate the mill for exactly 5000 revolutions.
6. Rinse the entire contents of the mill jar (slurry and grinding elements) onto an upper 3.35 mm (6 mesh) sieve and underlying 75 μm (200 mesh) sieve with distilled water. The grinding elements are retained on the upper 3.35 mm sieve and should be washed thoroughly to remove all rock particles.
7. After washing, remove the 3.35 mm sieve and grinding elements. Wet sieve the sample on the 75 μm sieve. Retain and dry the <75 μm fraction passed through the sieve.
8. Dry and weigh (to the nearest 0.01 g) the >75 μm residue remaining on the sieve (W2).
9. After weighing, re-combine the >75 μm and <75 μm sieve fractions.

Calculation
Calculate grindability index as follows:

Grindability index (GI) (%) = [(W1 - W2) / W1] x 100

The results of the laboratory trials using Zambian limestone and dolomite samples are given in Tables C11 and C12.

Table C11. Grindability index results.

Sample	Crystal size	Sample type	Grindability index (%<0.075 mm)
280	Coarse	Dolomite	63.98
281	Coarse	Limestone	67.23
282	Very fine	Dolomitic limestone	84.16
283	Fine-to medium	Limestone	78.60
284a	Medium	Dolomite	37.30
284b	Medium-to-coarse	Dolomite	44.81
285	Medium-to-Coarse	Dolomite	51.26
290	Fine	Limestone	93.58

Table C12. Replicate grindability index test results.

Sample	Test 1	Test 2	Test 3	Test 4	Test 5	Mean	SD	Coefficient of variation (%)
284	49.32	44.30	40.10	47.19	49.56	46.10	3.96	8.59
290	92.94	91.35	90.58	94.77	91.76	92.28	1.63	1.77

APPENDIX C5:
RECOMMENDED METHODS FOR TESTING LIMESTONE AND DOLOMITE FOR AGRICULTURAL LIME USE

Method 4. Sieve analysis of agricultural liming materials (after ASTM C602-95)

Note: this procedure should be carried out on the product obtained from the grinding index test (method 3 above).

Apparatus
Drying oven
Balance
Air-tight container
Hard rubber roller
8 inch (203 mm) No.8 (2.36 mm) sieve
8 inch (203 mm) No.60 (250 μm) sieve

Procedure

1. Dry the sample to constant weight at 110±5°C and store in an air-tight container. Use a riffle box, sample splitter or quartering method (see ASTM D3176) to obtain a 100-150 g sub-sample.
2 Agglomeration of fine particles can occur in limestones containing clay. These agglomerates should be broken by gently rolling the dry sample (e.g. with a hard rubber roller) without crushing limestone particles.
3. Weigh the dried sample to an accuracy of 0.1 g. Sieve the sample through an 8 inch (203 mm) diameter No.8 (2.36 mm) sieve and an 8 inch (203 mm) diameter No.60 (250 μm) sieve conforming to specification ASTM E11.
4. Samples should be shaken through both lateral and vertical movement of the sieve. This should be accompanied by periodic jarring to ensure continuous movement of the sample over surface of the sieve.
5. Continue sieving until <0.5% of the total weight passes either sieve during 1 minute of operation.
6. Calculate the amount of material passing 2.36 mm and 250 μm to the nearest weight percent of dry sample
7. If required, calculate moisture content as follows:
Moisture (%) = 100 x (wt. as received - dry wt.) / wt. as received

APPENDIX C6:
RECOMMENDED METHODS FOR TESTING LIMESTONE AND DOLOMITE FOR AGRICULTURAL LIME USE

Method 5. Reactivity by the resin suspension method (after Bornman et al., 1988)

Note: this procedure should be carried out on the product obtained from the grinding index test (method 3 above).

Reagents
500 g Amberlite ® CG-50 ion exchange resin*
(200 to 400 mesh grade, CEC = 10 cmol p+ Kg-1)
1 litre acetic acid, concentrated
100g calcium carbonate, analytical grade, micronized or reprecipitated

*Supplier:
Product number 20211-5000
Fisher Scientific UK
Bishop Meadow Road
Loughborough, Leicestershire
LE11 0RG United Kingdom
Tel + 44 1509 231166

Apparatus
600 ml glass beakers (x10)
Watch glasses (x10)
50 ml measuring cylinder
500 ml plastic bottle
Glass stirring rod (x10)
pH meter and pH calibration buffer solutions
500 ml measuring cylinder
5 litre plastic container

Preparation of dilute acetic acid (pH 4.0)
1. Pipette 3 ml of concentrated acetic acid into a 500 ml plastic container. Add 500 ml of distilled water and mix thoroughly. Label and retain solution.
2. Decant a 20 ml aliquot of this solution into a measuring cylinder. Transfer to a 5 litre plastic bottle and dilute with distilled water to 5 litres. Check that the pH of this dilute acetic acid is around pH 4 (± 0.05 pH units). This dilute acetic acid solution is used for the reactivity experiment.

Procedure
1. Weigh out 1.000 g of resin (± 0.001 g). Transfer to a 600 ml beaker
2. Weigh out 0.200 g of sample (± 0.001 g). Transfer to the 600 ml beaker.
3. For each sample, repeat steps 1 and 2 to obtain a duplicate.
4. Add 500 ml of dilute acetic acid solution from a measuring cylinder
5. Stir the suspension vigorously for 1 minute with the glass stirring rod and then cover with watch glass
6. Allow beaker and contents to stand at room temperature (25¡C) for a period of 24 hours.

7. Calibrate pH meter for an acid pH range.
8. After a 24 hour period has elapsed, stir the suspension vigorously for 1 minute with the glass stirring rod. Allow to settle, immerse pH electrode and record the pH after 15 minutes.
9. For each batch of samples tested, a control sample and a blank sample need to be included. 0.200 g ($\pm$ 0.001 g) of analytical grade CaCO3 (reprecipitated or micronized) is used as the control sample. For the blank sample, 1.000 g ($\pm$ 0.001 g) of ion-exchange resin is used with no sample addition. Duplicate analyses for both blank and control are also necessary.
10. Average the two pH reading obtained from the duplicate analyses. (Note: Bornman et al. suggest that results are discarded and the whole test repeated if the pH of the duplicates differ by more than 0.1 pH unit.)

Calculation
Reactivity (%) = [(pHL - pH0) / (pHC - pH0)] x 100
Where
pHL = pH of sample after 24 hours
pHC = pH of control after 24 hours
pH0 = pH of blank after 24 hours

The results of the laboratory trial using Zambian limestone and dolomite samples are given in Table C13

Table C13. Reactivity by ion-exchange resin method (Bornman et al., 1988). Fineness factor and grindability index data included for comparison

Sample		Fineness factor (%)	Grindability index (%)	Average Reactivity (%)	Test 1 Reactivity (%)	Test 2 Reactivity (%)	Test 3 Reactivity (%)	SD	Coefficient of Variation (%)
280	Dolomite	82.63	63.98	65.94	74.63	57.14	66.06	8.74	13.26
281	Limestone	90.94	67.23	86.78	91.54	84.85	83.94	4.15	4.78
282	Dolomitic limestone	81.37	84.16	89.26	88.06	93.94	85.77	4.22	4.72
283	Limestone	98.51	78.60	91.58	101.00	90.91	82.85	9.09	9.93
284a	Dolomite	99.28	37.30	63.82	53.73	75.32	62.41	10.87	17.03
284b	Dolomite	99.43	44.81	76.96	75.12	78.79	ND	2.59	3.37
285	Dolomite	90.35	51.26	71.68	67.16	76.19	ND	6.38	8.90
287	Limestone	97.36	55.61	77.32	74.13	80.52	ND	4.52	5.84
288	Agricultural lime	97.26	23.64	62.44	51.24	74.03	62.04	11.40	18.25
289	Agricultural lime	96.34	28.24	63.78	56.22	74.89	60.22	9.83	15.42
290	Limestone	92.71	93.58	99.66	101.49	97.84	ND	2.59	2.59
Average									9.46

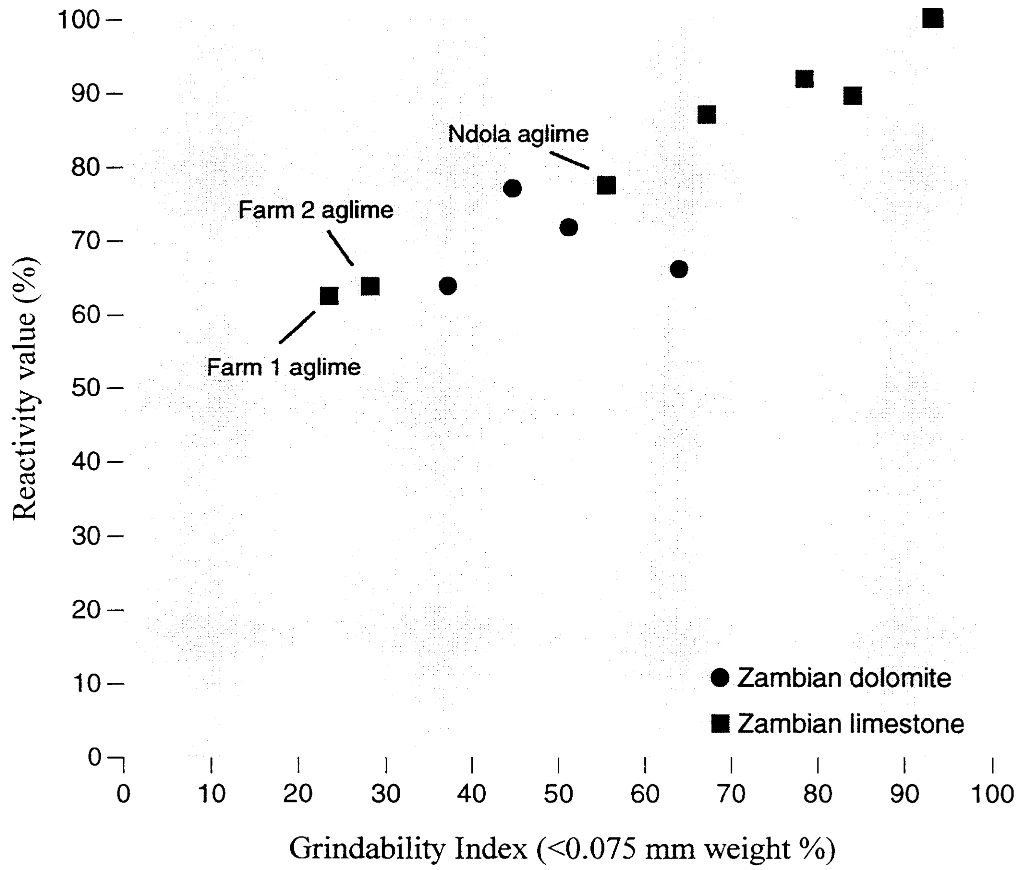

Figure C1. Plot of reactivity Vs grindability for some Zambian limestone and dolomite samples (including three agricultural lime samples from Zambia).

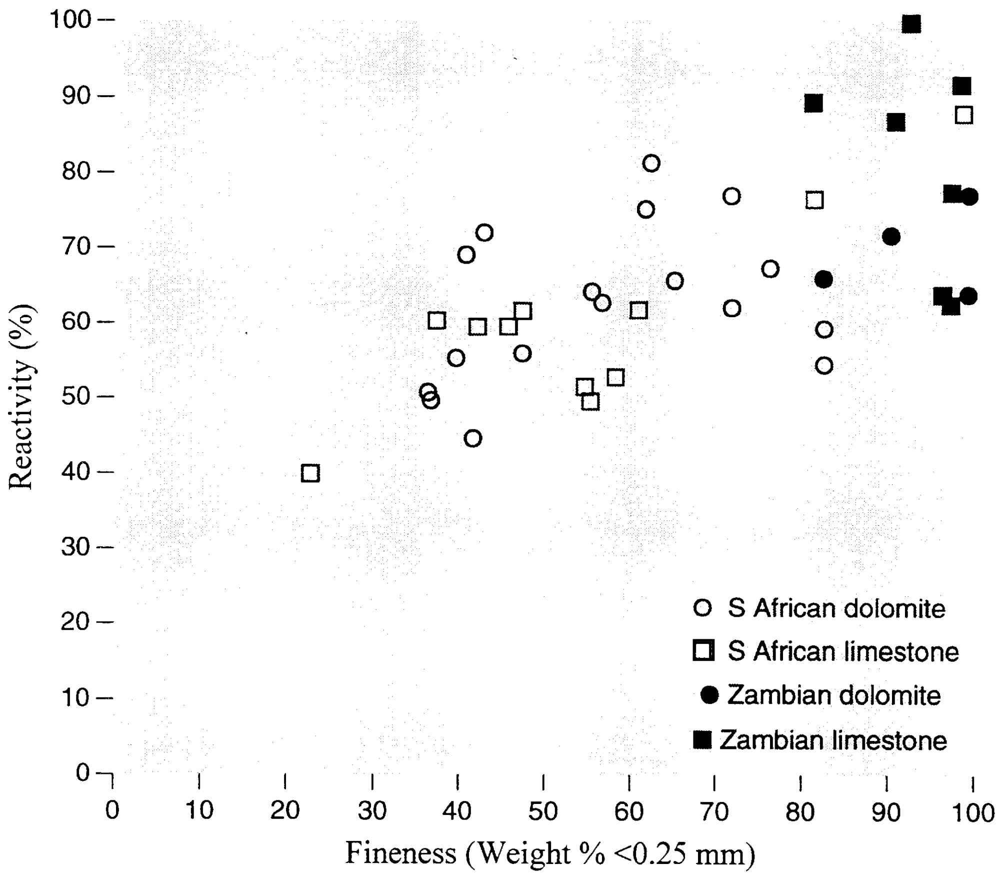

Figure C2. Plots of reactivity Vs fineness. Comparison of Zambian limestone & dolomites with South African agricultural lime samples (Bornman et al., 1988).

SECTION D:
LIME EVALUATION PROGRAMME: FINDINGS & RESULTS

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1. INTRODUCTION

A suite of limestone and dolomite samples from across Zambia was collected and analysed as part of the lime evaluation programme of the project. The samples were evaluated to determine their suitability for use as agricultural lime (aglime). Field work was carried out over a 12 month period, during which time 36 samples were collected (Appendix D1). These samples were analysed at the British Geological Survey (BGS) and at the Geological Survey Department (GSD) of Zambia. The BGS determined the mineralogy (by petrographic analyses, Appendix D2) and the major element chemistry (by XRF, Appendix D3) of each sample. The GSD determined the CaO / MgO content, Neutralisation Value (NV), reactivity and grindability of each sample (Appendix D3).

2. METHODS

2.1. Field sampling & preparation

Thirty five samples of limestone and dolomite were collected from across Zambia (Appendix D1). Spot samples, (5 - 10 kg), were collected; multiple samples were taken from some localities in order to accommodate lithological variations. Each sample was assigned a "Z" number and a corresponding BGS collectors number (prefix "CJM"). The GSD carried out the preparation (Figure D1) of the samples for analysis as follows:

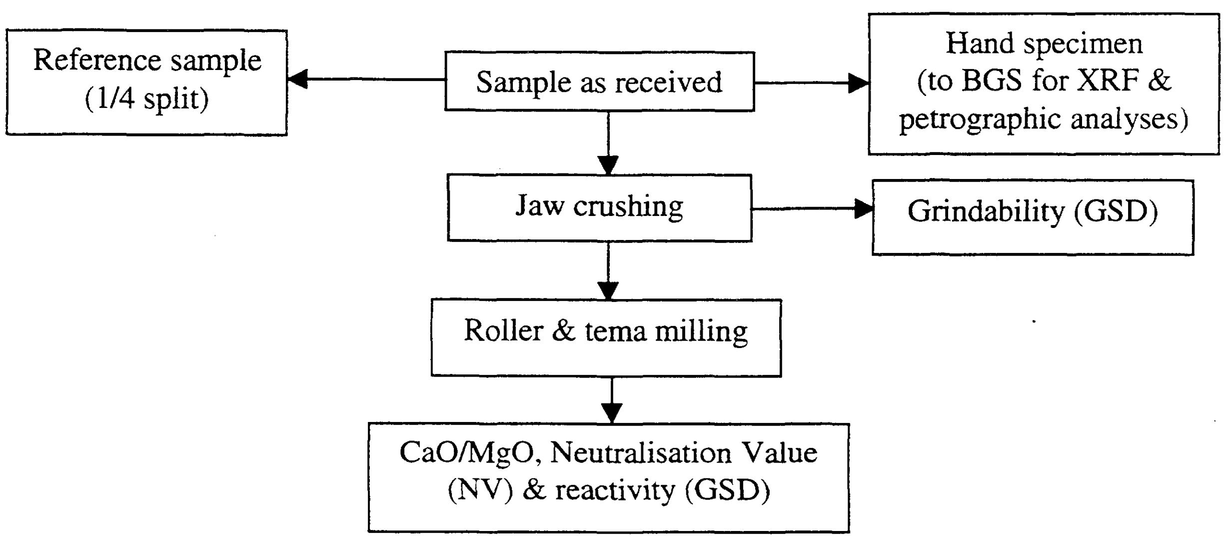

Figure D1. Preparation of limestone & dolomite for analysis

2.2. Test methods

The mineralogy of the samples was determined by petrographic analysis. For each sample standard thin sections were made and stained with potassium ferricyanide and alizarin red S to aid identification of ferroan and non-ferroan calcite and dolomite. A concise description of the mineralogy and texture of the samples was produced by examination of the thin sections using a Zeiss binocular microscope.

The chemistry of the samples was determined by X-ray fluorescence analysis. The samples were analysed to determine the major element chemistry using a Phillips PW 1480 X-ray fluorescence (XRF) spectrophotometer.

The calcium and magnesium oxide (CaO & MgO) content, Neutralisation Value (NV), reactivity and grindability of each sample were determined according to the methods outlined in Section C (Plate D2).

3. RESULTS & DISCUSSION

The results are given in full in Appendices D2 (mineralogy) and D3 (chemistry, neutralisation value, reactivity and grindability).

The petrographic analysis identified eight distinct lithologies within the sample group including dolomitic marble (13 samples), marble (9), dolomite (5), calcrete (2), mudstone (2), sandstone (2), siltstone (1) and marly sandstone (1). The test results for the main carbonate lithologies are summarised in Table D1.

Table D1. Summary of limestone & dolomite test results

Lithology	CaO* Wt %	MgO* Wt %	Neutralising Value % CCE	Reactivity %	Grindability Wt % <75 μm
Dolomitic marble	19.62 - 51.84	3.47 - 22.59	34 - 107	63.2 - 89.3	41.1 - 98.7
Average	**30.13**	**17.76**	**75**	**70.1**	**83.7**
Marble	41.68 - 55.59	0.22 - 3.23	73 - 99	79.0 - 91.6	67.2 - 97.5
Average	**51.45**	**1.14**	**84**	**86.7**	**87.1**
Dolomite	25.08 - 34.40	18.59 - 21.55	96 - 105	68.42 - 89.34	97.12 - 98.63
Average	**31.65**	**20.68**	**105**	**78.91**	**97.75**

NB CCE = Calcium Carbonate Equivalent. * = XRF values

As discussed in Section C, the most important properties for effective aglime are the Neutralising Value (NV) and the particle-size distribution. The particle-size is ultimately a function of the energy applied during grinding and is therefore not a useful means of evaluating the suitability of limestone and dolomite for use as aglime. Therefore the Neutralisation Value is the single most important criterion in such an evaluation. A Neutralisation Value of 80% Calcium Carbonate Equivalent is considered to be a minimum for aglime. On this basis, 16 of the samples evaluated are worthy of further consideration.

Another important property of aglime is the provision of plant nutrient, especially magnesium. A magnesium oxide content of 6% is considered to be a minimum for aglime. Eight of the 16 samples, identified as having appropriate Neutralisation Values, exceed this requirement. The properties of the eight samples are as follows:

Table D2. Samples with potential for use as agricultural lime

Sample	Neutralisation Value % CCE	MgO Wt %	CaO Wt %	Reactivity %	Grindablity % < 75 µm
1 Dolomitic marble Chivuna Limestone, Chivuna	106	21.83	30.24	65.9	64.0
5. Dolomitic marble Mujimbeji Marble, Solwezi	107	21.86	30.96	70.4	41.1
6. Dolomitic marble Mujimbeji Marble, Chombela	107	20.08	33.06	71.7	51.3
10. Dolomite Upper Roan Fm, Mpongwe	105	18.59	43.4	89.3	97.1
11. Dolomite Muchinda Limestone, Lilyvale Farm, Kabwe	106	21.55	31.22	84.2	97.2
18. Dolomite Mujimbeji Marble, Lukunyi	106	21.31	30.93	73.7	98.0
29. Dolomitic marble Lower Roan Fm, Mkushi	103	20.94	29.6	63.2	98.4
30. Dolomitic marble Lower Roan Fm, Mkushi	104	21.25	30.04	68.4	98.6

The grindability and reactivity give indications of the relative ease of production of aglime, and also the likely performance after application.

4. CONCLUSIONS

i) The carbonate rocks collected as part of the lime evaluation programme mainly consisted of dolomitic marble, marble and dolomite.

ii) Use of the Neutralisation Value (NV) and magnesium oxide (MgO) content enabled the samples to be 'screened' as to their potential for use as aglime.

iii) The dolomite and dolomitic marble samples identified as having the potential for use as aglime have the following typical properties:

   i) Neutralisation Values in excess of 100% CCE.
   ii) Magnesium oxide content between 18 and 22% MgO.
   iii) Calcium oxide contents between 30 and 43% CaO.
   iv) Reactivity values between 63 and 89%.
   v) Grindability values between 41 and 98%.

APPENDIX D1: LIME EVALUATION SAMPLING PROGRAMME - SAMPLE LIST

GSD No. Z	BGS No. CJM	Locality name	1:50K Topo Grid ref	Lithological description	Lithostratigraphy
1	280	Chivuna	1627 B2 NN 855 120	White, coarsely crystalline, hard, compact marble	Chivuna Limestone, Chivuna Formation, Monze Group, Katanga
2	281	Masangu	1628 A1 PN 116 299	Friable, coarse grained marble	Upper Chilumbwe Fm ?, Undifferentiated Katanga
3	282	Ndola lime footwall	1:250K CB 685 8574	White, fine grained, thinly bedded dolomitic limestone	Kakontwe Limestone, Lower Kundelungu Fm, Kundelungu Group, Katanga
4	283	Ndola lime hanging wall	1:250K CB 685 8574	White, fine grained, thinly bedded dolomitic limestone	Kakontwe Limestone, Lower Kundelungu Fm, Kundelungu Group, Katanga
5	284	Solwezi South	1226 A2 MS 359 524	White, medium grained, friable dolomite	Chafugoma (Wamikumbi) Fm, Monze Group, Katanga
6	285	Chombela	1226 B3 MS 516 335	Pinkish-brown marble	Chafugoma (Wamikumbi) Fm, Monze Group, Katanga
7	286	Matanda	No detail	Reddish-purple, fine grained siltstone	
8	326	Lake Kashiba	1327 B4 PR 018 039	Dark grey, medium grained, friable marble.	Upper Roan Fm, Mine Series Group, Katanga
9	327	St. Anthonys Mission	1327 B4 PR 015 121	Salmon pink - pinkish brown, fine grained, hard, compact marble	Upper Roan Fm, Mine Series Group, Katanga
10	328	Bweembelelo	1328 C1 PR 327 031	White - whitish grey, powdery surface, fine grained, sugary texture marble	Upper Roan Fm, Mine Series Group, Katanga
11	329	Lilyvale Farm	1428 A3 PQ 328 001	Buff-grey, fine grained, hard, compact marble (Feed for agricultural lime production)	Muchinda Limestone ?, Nyama Fm, Kundelungu Group, Katanga
12	330	Lilyvale Farm	1428 A3 PQ 328 001	Dark grey medium grained, hard, compact marble (Feed for stock feed production)	Muchinda Limestone ?, Nyama Fm, Kundelungu Group, Katanga
13	331B	Sichibende	1430 D2/D4 TU 801 611	Yellowish grey coarse grained massive marble	Mvuvye Marble, Mvuvye Group, Undifferentiated Katanga

APPENDIX D1: LIME EVALUATION SAMPLING PROGRAMME - SAMPLE LIST

GSD No. Z	BGS No. CJM	Locality name	1:50K Topo Grid ref	Lithological description	Lithostratigraphy
14	338	Hofmeyer	1430 D2/D4 TU 698 752	Greenish brown coarse grained hard marble	Mvuvye Marble, Mvuvye Group, Undifferentiated Katanga
15	339	Jam	1430 D2/D4 TU 582 824	Yellowish brown coarse grained friable marble	Mvuvye Marble, Mvuvye Group, Undifferentiated Katanga
16	340	Mkonda	1431 A1 UV 071 477 ?	Grey medium grained friable marble	Mvuvye Marble, Mvuvye Group, Undifferentiated Katanga
17	341	Mupeta	1430 D2/D4 TU 778 665	Greyish brown fine grained hard compact marble	Mvuvye Marble, Mvuvye Group, Undifferentiated Katanga
18	342	Lukunyi	1323 A (100 K) 541 721	Greyish brown fine grained hard compact marble	Chafugoma (Wamikumbi) Fm, Monze Group, Katanga
19	343	Mandanji, Ndondo	1324 A4 078 104	Light grey fine grained hard compact dolomitic limestone	Chafugoma (Wamikumbi) Fm, Monze Group, Katanga
20	344	Manyinga	1324 A4 113 139	Grey fine grained mudstone (with limestone concretions)	Chafugoma (Wamikumbi) Fm, Monze Group, Katanga
21	345	Chingola	1227 D2 169 935	Whitish brown fine grained hard compact laminated dolomite	Barangu Dolomite, Upper Kundelungu Fm, Kundelungu Group, Katanga
22	346	Chingola	1227 D2 169 935	Grey fine grained interbanded dolomitic schist (?)	Barangu Dolomite, Upper Kundelungu Fm, Kundelungu Group, Katanga
23	347	Nkombwa	1032 B2 830 780	Whitish brown medium grained hard compact calcitic dolomite	Carbonatite
24	348	Nkombwa	1032 B2 835 776	Grey coarse grained hard compact calcitic dolomite	Carbonatite
25	349	Nkombwa	1032 B2 835 771	Light grey medium grained friable marble	Carbonatite
26	350	Mpangala	1032 B3 468 426	White fine grained travertine	Mpangala Marble, Manshya Group, Muva

APPENDIX D1: LIME EVALUATION SAMPLING PROGRAMME - SAMPLE LIST

GSD No. Z	BGS No. CJM	Locality name	1:50K Topo Grid ref	Lithological description	Lithostratigraphy
27	351	Mpangala	1032 B3 471 424	Yellowish brown fine grained hard compact pelite	Mpangala Marble, Manshya Group, Muva
28	352	Mpangala	1032 B3 470 425	White medium grained hard compact pelite	Mpangala Marble, Manshya Group, Muva
29	353	Mkushi	1329 A3 QR 432 125	Light grey - grey, medium grained, laminated marble	Lower Roan Fm, Mine Series Group, Katanga
30	354	Mkushi	1329 A3 QR 32 125	Light grey - grey, medium grained, laminated marble	Lower Roan Fm, Mine Series Group, Katanga
31	355	Mkushi	1329 A3 QR 432 125	Light grey - grey, medium grained, laminated marble	Lower Roan Fm, Mine Series Group, Katanga
32	356	Matanda	1128 A4 PT 579 421	Pinkish-grey, laminated, compact medium grained marble	Luapula Beds, Upper Kundelungu Fm, Kundelungu Group, Katanga
33	357	Matanda	1128 A4 PT 583 418	Pinkish-grey, laminated, compact medium grained marble	Luapula Beds, Upper Kundelungu Fm, Kundelungu Group, Katanga
34	359	Chipata	1332 A1 152 544	Grey coarse grained hard compact marble	Basement Complex
35	360	Chipata	1332 A1 161 552	Grey medium grained hard compact marble	Basement Complex
36	358	Nampundwe	1527 B4 NN 979 871	Dark - light grey medium grained hard compact marble with appreciable pyrite 'layers'	Mampompo Limestone, Mampompo (Cheta) Formation, Broken Hill Group, Katanga

APPENDIX D2:
PETROGRAPHY OF LIMESTONE & DOLOMITE FROM ZAMBIA

DJ Harrison
Mineralogy & Petrology group, British Geological Survey, UK

1. **Dolomitic marble, Chivuna Limestone, Chivuna, Southern Province**
   Coarse equigranular mosaic of interlocking dolomite crystals. Original structure totally destroyed. Scattered long needle and columnar shaped crystals (? tremolite).

2. **Marble, Upper Chilumbwe Formation, Masangu, Southern Province**
   Coarse grained, equigranular mosaic of interlocking calcite crystals with common irregular vughy porosity (small, elongate, sub-parallel cavity - the rock should have a fabric). Common, scattered sub-rounded quartz grains (fine to medium sand size). Scattered irregular, small crystals of calc-silicate (? diopside).

3. **Dolomitic marble, Kakontwe Limestone, Ndola Lime Ltd, Copperbelt Province**
   Very fine grained (very fine sand size) mosaic of calcite crystals with patchy development of fine or medium grained crystals. Minor finely grained dolomite as matrix between calcite crystals. Traces of argillaceous lamination. Rare carbonaceous clay coated stylolitic surfaces. Fissured and veined with coarsely crystalline calcite. Rare, widely scattered crystals of calc-silicate mineral (? diopside) and fine grained opaques (? pyrite).

4. **Marble, Kakontwe Limestone, Ndola Lime Ltd, Copperbelt Province**
   Equigranular mosaic of interlocking fine to medium calcite crystals. Traces of crystalline lamination, otherwise original texture completely destroyed.

5a. **Dolomitic marble, Mujimbeji Marble, Solwezi, North-western Province**
   Medium grained equigranular mosaic of interlocking dolomite crystals. Extremely uniform in grain size and texture. Crystals show slight preferred orientation; original rock may show a layered fabric.

5b. **Dolomitic marble, Mujimbeji Marble, Solwezi, North-western Province**
   Medium grained equigranular mosaic of interlocking dolomite crystals. Extremely uniform in grain size and texture. Scattered small prismatic crystals of ? tremolite.

6. **Dolomitic marble, Mujimbeji Marble, Chombela, North-western Province**
   Medium and coarse grained mosaic of interlocking dolomite crystals, scattered calcite crystals. Minor vughy porosity. Carbonaceous streaks, may be original lamination. Rare prismatic crystals of unidentified calc-silicate mineral.

7. **Siltstone, Matanda, Luapula Province**
   Fine grained, laminated. Fine sand sized quartz grains and rare feldspar grains interlaminated with silt and carbonaceous clay layers. Sand grains are dominantly angular or sub-angular. Scattered thin tabular crystals (? mica, ? chlorite) parallel to lamination.

8. **Marble, Upper Roan Formation, Lake Kashiba, Mpongwe, Copperbelt Province**
   Fine to medium grained, laminated, some coarse grained laminae. Orientation of grains, parallel to lamination. Recrystallised fabric (interlocking mosaic of secondary crystals). Finer grained laminae contain black carbonaceous patches/ streaks and diffuse grain coatings. Widely scattered fine grains of opaque mineral - pyrite? Scattered prismatic/flaky crystals of apatite, mainly in fine grained laminae.

9. **Marble, Upper Roan Formation, St,Anthonys Mission, Mpongwe, Copperbelt Province**
   Medium grained mosaic of equant interlocking calcite crystals.Very widely scattered small tremolite crystals and feldspar grains. Some finer grained laminae and argillaceous streaks. Minor fracturing and vughy porosity.

10. **Dolomite, Upper Roan Formation, Bweembelelo, Mpongwe, Copperbelt Province**
Very fine grained granular dolomite crystals with veins and irregular patches of coarse grained calcite (partially ferroan). Thin veinlets of ferroan calcite. Minor silicification of calcite vein fillings.

11. **Dolomite, Muchinda Limestone, Lilyvale Farm, Kabwe, Central Province**
Predominantly fine to medium grained mosaic of subhedral and euhedral dolomite crystals with patches of coarse grained dolomite. Widely scattered medium grained crystals of pyrite.

12. **Marble, Muchinda Limestone, Lilyvale Farm, Kabwe, Central Province**
Laminated, mix of fine to coarse grained calcite crystals, with the large crystals showing strong cleavage. Scattered, relatively common, medium grained subhedral and euhedral feldspar crystals. Rare quartz grains. Widely scattered fine to medium opaque mineral - pyrite? Occasional stylolites with carbonaceous and pyrite coatings.

13. **Marble, Mvuvye Marble, Sichibende, Eastern Province**
Mosaic of interlocking coarse grained ferroan calcite crystals with common medium grained quartz crystals and less common medium grained diopside and biotite. Minor feldspar (anorthite ?) and sphene. Scattered fine to medium opaque (magnetite?) grains.

14. **Marble, Mvuvye Marble, Hofmeyer, Eastern Province**
Mosaic of medium/coarse interlocking calcite cryatals with some patches of ferroan calcite. Common medium/coarse diopside, less common scapolite, quartz, rutile, tremolite and mica. Rare fine to medium opaque (magnetite?) grains.

15. **Marble, Mvuvye Marble, Jamu, Eastern Province**
Coarsely crystalline mosaic of calcite (slightly ferroan) crystals with common medium/coarse grains of scapolite and diopside. Scattered small quartz and mica crystals and relatively rare crystals of apatite. Scattered small opaque grains.

16. **Marble, Mvuvye Marble, Mkonda, Eastern Province**
Medium/coarse grained mosaic of interlocking calcite crystals with common medium quartz crystals and large diopside and scapolite crystals. Common opaque grains.

17. **Dolomitic marble, Mvuvye Marble, Mupeta, Eastern Province**
Mosaic of medium/coarse dolomite crystals with large irregular crystals of partially sericitised diopside and common flakes of mica.

18. **Dolomite, Mujimbeji Marble, Lukunyi, North-western Province**
Very fine grained lime mudstone (micrite), trace of organic structures (algal origin?). Scattered opaque grains (pyrite?). Rare small flakes of mica. Fractured, with fracture surfaces coated with carbonaceous material.

19. **Calcareous siltstone (calcrete), associated with Mujimbeji Marble, Mandanji, Ndondo, North-western Province**
Frequent fine and medium quartz (sand) grains with rare feldspar grains in a clay matrix. Scattered coarse calcite-encrusted nodules (with the appearance of algal nodules).Fine calcite cement also partially coats many sand grains.

20. **Marly sandstone, associated with Mujimbeji Marble, Mandanji, Ndondo, North-western Province**
Abundant fine quartz sand grains with scattered medium quartz grains in a calcareous clay matrix. Approximately 70% quartz, 30% clay matrix.

21. **Dolomitic marble, Barangu Dolomite, Chingola, Copperbelt Province**
Medium grained mosaic of interlocking dolomite crystals with common thin, scaly crystals of mica with strong, preferred alignment.

22. **Dolomitic marble, Barangu Dolomite, Chingola, Copperbelt Province**
Medium to very coarse mosaic of dolomite crystals (partially ferroan) with irregular patches of chlorite, minor flaky aggregates of mica.Scattered opaque grains and aggregates.

23. **Dolomitic marble, Carbonatite, Nkombwa Hill, Isoka, Northern Province**
Fine grained mosaic of equant dolomite crystals, with scattered coarser dolomite crystals, some of which are ferroan. Scattered quartz grains and patchy silicification. Rare tremolite and flakes of mica. Common opaque grains.

24. **Dolomitic marble, Carbonatite, Nkombwa Hill, Isoka, Northern Province**
Mosaic of medium grained interlocking ferroan dolomite crystals. Patchy concentrations of opaque grains with minor mica.

25. **Dolomitic marble, Carbonatite, Nkombwa Hill, Isoka, Northern Province**
Mostly coarse to medium mosaic of ferroan dolomite crystals. Some finer grained patches. Patchy concentrations of opaque grains.

26. **Calcrete, Mpangala Marble, Mpangala, Northern Province**
Mudstone, with calcite-filled cavities (algal origins?) and calcite encrusted nodules. Scattered fine to coarse quartz sand grains and microcrystalline quartz grains. Rare sericitised feldspar grains.

27. **Sandstone, Mpangala Marble, Mpangala, Northern Province**
Very fine sand sized quartz grains, sporadic opaques, minor micaceous matrix, locally common in patches. Well cemented, negligible porosity.

28. **Sandstone, Mpangala Marble, Mpangala, Northern Province**
Mainly very fine sand sized quartz grains, but with sporadic medium grains. Minor micaceous matrix.Rare augite crystals, rare opaques. Well cemented, negligible porosity.

29. **Dolomitic marble, Lower Roan Formation, Mkushi, Central Province**
Very fine grained mosaic of dolomite crystals with irregular patches of coarser grained dolomite and dolomite veinlets. Traces of original sedimentary structures. Minor sporadic silicification. Widely scattered fine mica crystals.

30. **Dolomite, Lower Roan Formation, Mkushi, Central Province**
Very fine grained mosaic of dolomite crystals with coarse grained dolomite vein fillings.Trace small crystals of quartz and mica.

31. **Dolomite, Lower Roan Formation, Mkushi, Central Province**
Very fine grained, laminated argillaceous dolomite with common thin tabular and scaly crystals of mica. Widely scattered fine quartz crystals.

32. **Mudstone, Luapula Beds, Matanda, Luapula Province**
Laminated, scattered veinlets of dolomite and silica. Sporadic fine crystals of quartz and mica. Minor ferroan dolomite filled micro-cavities.

33. **Mudstone, Luapula Beds, Matanda, Luapula Province**
Laminated with ferroan dolomite cement filling small cavities. Sporadic fine quartz and mica crystals.

36. **Dolomitic marble, Mampompo Limestone, Nampundwe Pyrite Mine, Lusaka Province**
Fine to coarse grained mosaic of ferroan dolomite crystals. Common, medium to coarse grained feldspar crystals. Patchy, relatively common opaque minerals.

APPENDIX D3: TEST RESULTS

Sample	CaO		MgO		NV	Reactivity	Grind-	Major oxides (XRF)														
No. (Z)	Wet	XRF	Wet	XRF			ability	SiO2	TiO2	Al2O3	Fe2O3	Mn3O4	Na2O	K2O	P2O5	SO3	Cr2O3	SrO	ZrO2	BaO	LOI	Total*
1	31.30	30.24	25.39	21.83	105.80	65.94	63.98	1.00	0.01	0.24	0.27	0.00	0.01	0.11	0.01	nd	nd	nd	nd	nd	46.33	100.05
2	53.88	55.14	0.68	0.22	97.30	86.78	67.23	1.37	0.01	0.23	0.15	0.00	0.05	0.07	0.02	nd	nd	nd	nd	nd	42.92	100.18
3	51.57	51.84	3.20	3.47	98.70	89.26	84.16	0.76	0.00	0.24	0.12	0.00	0.02	0.10	0.11	nd	nd	nd	nd	nd	43.42	100.08
4	53.52	55.59	1.48	0.38	98.70	91.58	78.60	0.11	0.00	0.00	0.04	0.00	0.02	0.00	0.10	nd	nd	nd	nd	nd	43.35	99.59
5	30.47	30.96	23.64	21.86	106.70	70.39	41.06	0.02	0.00	0.00	0.12	0.02	0.01	0.01	0.09	nd	nd	nd	nd	nd	46.95	100.02
6	32.28	33.06	23.67	20.08	106.50	71.68	51.26	0.14	0.00	0.04	0.10	0.02	0.01	0.02	0.10	nd	nd	nd	nd	nd	46.50	100.07
7	nd	2.05	nd	4.73	nd	nd	nd	55.96	0.83	17.53	6.82	0.04	1.07	4.50	0.17	nd	nd	nd	nd	nd	6.22	99.92
8	nd	55.34	nd	0.52	nd	nd	nd	0.66	0.01	0.17	0.13	0.01	0.06	0.02	0.20	nd	0.00	0.18	0.00	0.01	43.33	100.64
9	nd	55.17	nd	0.51	nd	nd	nd	0.57	0.01	0.18	0.12	0.01	0.06	0.02	0.21	0.00	0.00	0.17	0.00	0.00	43.31	100.36
10	35.75	34.40	19.23	18.59	105.02	89.34	97.12	0.37	0.00	0.06	0.38	0.02	0.04	0.00	0.02	0.01	0.00	0.03	0.00	0.00	46.46	100.38
11	36.97	31.22	19.14	21.55	105.86	84.21	97.23	0.14	0.00	0.05	0.16	0.01	0.01	0.00	0.01	nd	0.00	0.01	0.00	0.00	46.90	100.06
12	nd	55.75	nd	0.42	nd	nd	nd	0.19	0.01	0.03	0.22	0.01	0.01	0.00	0.03	nd	0.00	0.20	0.00	0.00	43.61	100.48
13	44.79	49.34	2.02	1.08	79.37	78.95	97.45	7.12	0.13	1.70	1.38	0.12	0.28	0.65	0.04	0.24	0.00	0.33	0.00	0.02	37.68	100.11
14	41.73	45.58	6.60	3.23	74.76	89.47	94.12	11.18	0.15	2.24	1.12	0.06	0.60	0.10	0.08	0.45	0.00	0.04	0.01	0.81	34.95	100.60
15	46.06	49.43	0.32	1.33	80.86	89.47	94.39	7.33	0.12	1.92	0.99	0.01	0.37	0.38	0.22	0.01	0.00	0.39	0.00	0.04	38.31	100.85
16	27.19	41.68	1.46	2.58	73.22	84.21	90.98	17.11	0.25	4.17	1.88	0.06	0.53	1.15	0.22	0.00	0.00	0.48	0.00	0.07	30.27	100.45
17	22.57	28.85	15.96	19.89	74.07	68.42	91.89	13.29	0.04	0.47	1.55	0.16	0.12	0.25	0.03	0.01	0.00	0.04	0.00	0.01	35.74	100.45
18	30.66	30.93	24.10	21.31	105.67	73.68	98.00	0.46	0.01	0.08	0.09	0.03	0.05	0.02	0.13	0.02	0.00	0.01	0.00	0.00	46.91	100.05
19	34.76	44.21	0.79	1.19	64.58	73.68	98.95	18.38	0.06	0.65	0.33	0.01	0.08	0.22	0.01	0.06	0.00	0.11	0.00	0.01	35.34	100.66
20	28.57	17.24	8.26	11.51	62.75	89.47	98.95	40.07	0.13	2.31	1.02	0.03	0.15	1.36	0.01	0.00	0.00	0.12	0.01	0.02	26.16	100.14
21	24.23	26.83	13.75	22.59	34.86	68.42	97.37	8.00	0.02	0.34	0.65	0.12	0.04	0.08	0.02	0.01	0.00	0.06	0.00	0.01	41.65	100.42
22	23.35	28.77	12.36	18.17	33.53	68.42	98.25	4.75	0.02	0.38	3.59	0.36	0.05	0.21	0.02	0.57	0.00	0.02	0.00	0.00	42.39	99.30
23	26.14	28.51	20.57	17.18	63.06	68.42	98.70	0.12	0.01	0.01	6.29	1.47	0.07	0.01	0.31	0.03	0.00	1.24	0.00	0.04	44.37	99.66
24	21.42	26.29	25.69	18.55	46.50	73.68	97.76	0.67	0.01	0.08	7.36	1.33	0.09	0.04	0.05	0.20	0.00	1.09	0.00	0.02	43.94	99.72
25	23.51	26.98	21.87	17.00	47.75	63.16	97.64	0.19	0.00	-0.01	9.25	1.49	0.06	0.00	0.28	0.33	0.00	1.18	0.00	0.14	42.63	99.52
26	37.75	42.40	8.09	5.00	84.03	73.68	98.91	10.28	0.16	1.90	0.90	0.02	0.11	0.34	0.02	0.03	0.00	0.02	0.00	0.04	39.38	100.60
27	0.42	0.08	0.12	0.32	1.25	nd	nd	89.68	0.16	5.47	0.27	0.00	0.09	3.23	0.00	0.00	0.00	0.00	0.05	0.05	0.65	100.05
28	0.67	0.63	0.10	0.31	1.60	nd	nd	90.21	0.22	4.32	0.28	0.00	0.09	2.28	0.01	0.01	0.00	0.00	0.08	0.04	1.15	99.63
29	29.55	29.60	19.58	20.94	102.94	63.16	98.35	2.51	0.03	0.39	0.39	0.05	0.05	0.24	0.02	0.02	0.00	0.02	0.00	0.00	45.68	99.94
30	29.59	30.04	22.61	21.25	103.94	68.42	98.63	1.27	0.03	0.44	0.35	0.04	0.04	0.29	0.02	0.01	0.00	0.02	0.00	0.00	46.18	99.98
31	26.27	25.08	23.04	18.91	96.34	68.42	97.99	11.51	0.22	3.25	0.48	0.04	0.13	1.51	0.12	0.01	0.01	0.01	0.00	0.02	39.01	100.31
32	29.15	29.36	21.58	19.09	83.08	68.42	94.23	4.74	0.07	1.43	0.77	0.39	0.23	0.38	0.09	0.19	0.00	0.01	0.00	0.01	43.59	100.35
33	30.84	31.20	19.96	17.36	83.21	68.42	94.17	4.94	0.07	1.46	0.65	0.61	0.41	0.23	0.07	0.18	0.00	0.01	0.00	0.02	43.18	100.39
34	20.67	30.39	15.45	20.06	77.72	63.16	96.43	3.95	0.02	0.29	0.88	0.04	0.07	0.01	0.02	0.12	0.00	0.01	0.00	0.00	44.80	100.66
35	22.78	21.20	13.29	13.44	78.34	63.16	96.12	4.48	0.20	2.20	19.00	0.18	0.14	0.18	0.06	11.18	0.00	0.02	0.00	0.00	21.22	93.50
36	nd	19.62	nd	11.52	nd	nd	nd	6.16	0.13	2.23	21.12	0.31	0.35	0.55	0.07	8.61	0.00	0.01	0.01	0.01	24.62	95.34

NB All values are weight percentages (wt %), except NV (Neutralisation Value) = % Calcium Carbonate Equivalent (CCE), Reactivity = % reactivity & Grindability = % <75 microns;
CaO & MgO values divided into: "Wet" ie wet chemical analysis and "XRF" ie X-ray fluorescence analsysis (all XRF by British Geological Survey, BGS); * = Totals include XRF CaO & MgO values
Wet chemical CaO & MgO determination, Neutralisation Value, Reactivity & Grindability mainly determined by Zambian Geological Survey Department (values for 1 - 6 carried out by BGS)

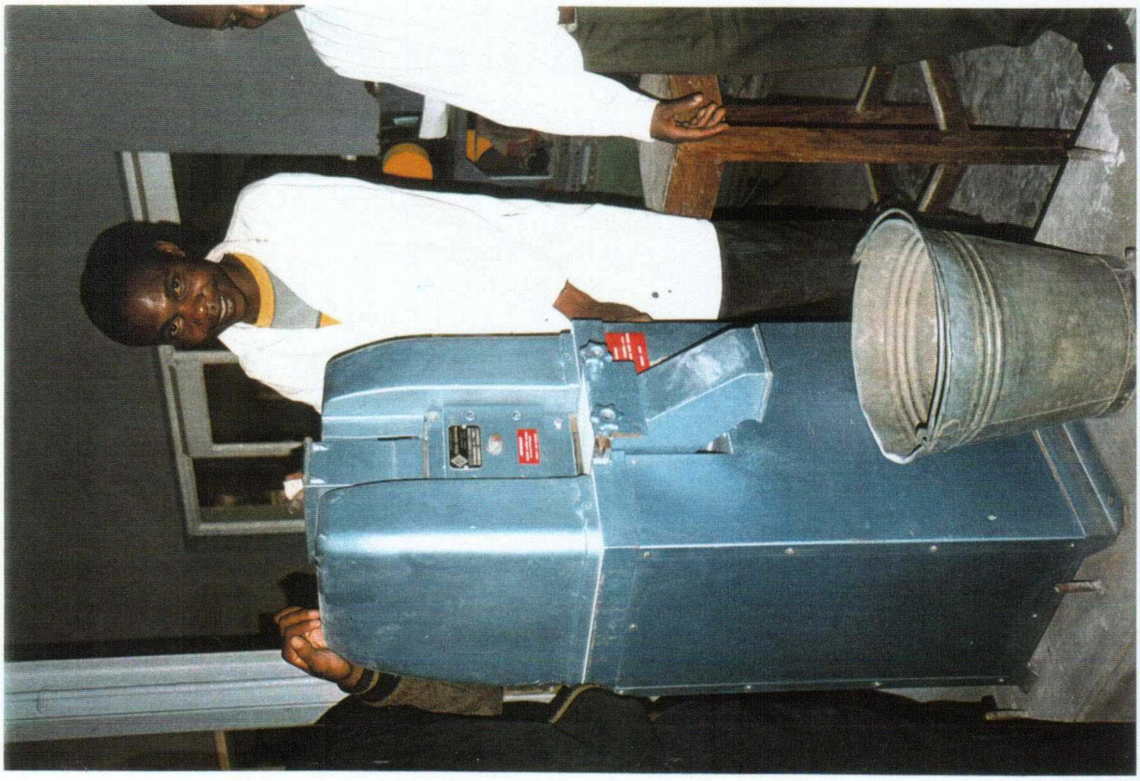

Plate D1. Preparation of carbonate samples for testing, GSD labs, Lusaka

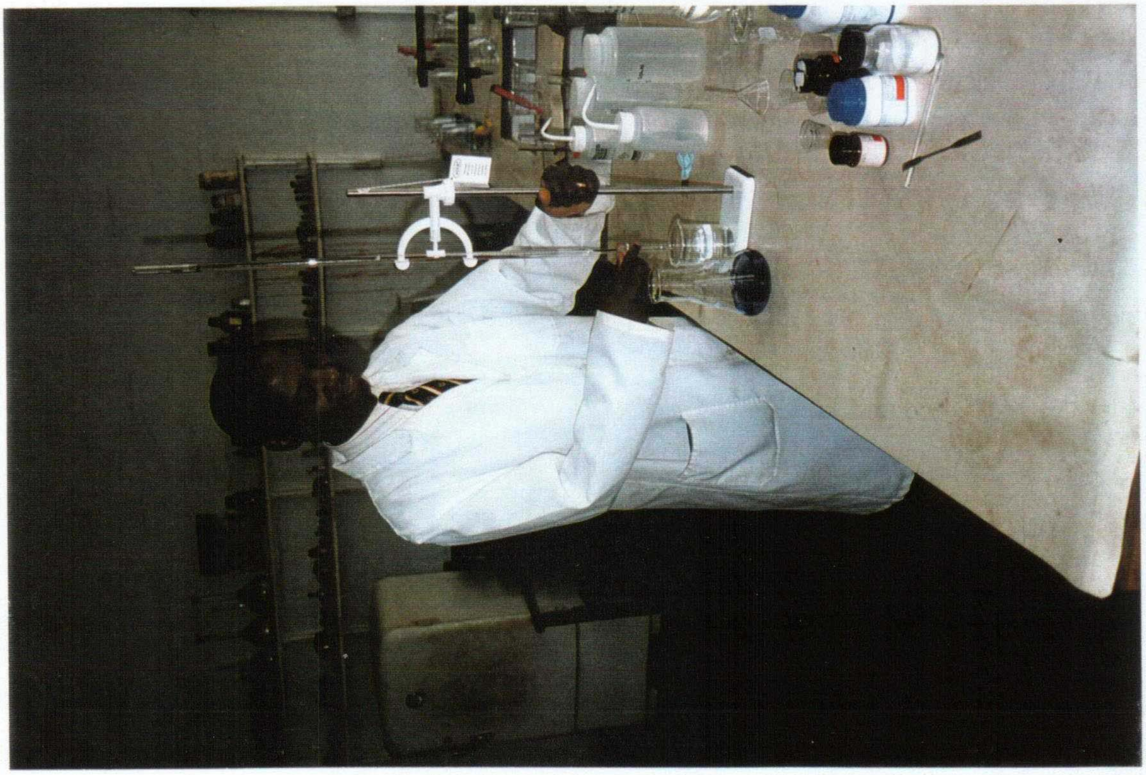

Plate D2. Testing of carbonate samples by GSD Geochemist (David Kapindula), GSD labs, Lusaka

SECTION E:
REVIEW OF SMALL-SCALE LIME PRODUCTION IN ZIMBABWE

This review of small-scale lime production was undertaken by Intermediate Technology Zimbabwe (ITZ).

LOCAL DEVELOPMENT OF AFFORDABLE LIME IN SOUTHERN AFRICA

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The British Geological Survey

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• LOCAL DEVELOPMENT OF AFFORDABLE LIME IN SOUTHERN AFRICA

1.0 BACKGROUND

Mining and mineral processing play an important role in the national economies of many developing countries. Besides creating employment and generating substantial revenue, products are produced for use within both the manufacturing and the agricultural industries.

For many years the mining sector in Southern Africa has been dominated by large trans-national companies which have the technical know-how, and huge financial resources normally associated with investments in the mining sector.

Most mineral deposits are however found in rural areas and in small reserves, and hence development of small-scale mining is one major way of stimulating rural development and curbing the rural to urban migration and its associated socio-economic problems. Small-scale mining also involves exploitation of mineral resources shunned by the large companies. Big companies want deposits with large reserves, which can be mined over a long period of time. Small-scale miners (small producers) therefore play a crucial role in tapping some of the mineral wealth.

In most southern African countries there are several large and small deposits of calcium and magnesium carbonate rich rocks which can be exploited to make affordable agricultural lime. Investigations into lime use and production by the Intermediate Technology Development Group in Zimbabwe (ITZ) have shown that use of agricultural lime as a soil conditioner is minimal especially among Southern Africa's small scale farmers who do not have knowledge on use of lime. Local demand for agricultural lime by small scale farmers could be improved by launching awareness programmes through demonstration projects.

Current production levels of agricultural lime are according to crop production experts in Southern Africa still very low. The few lime producers in the region also charge relatively high prices for lime, and at the same time they do not have decentralised outlets to cater for needs of farmers in remote areas. As a result only a few large-scale commercial farmers who can afford high transportation costs are using lime to improve their soils and consequently their crop yields.

2.0 THE STUDY

This study report discusses the different approaches to mining, and processing of calcium carbonate source rocks using different methods or technologies to produce agricultural lime. Agricultural lime is ,for the purposes of this study ,considered as being crushed carbonate rock, or calcined carbonate which has been hydrated to produce slaked lime which can be applied to fields by farmers in a powder form.

Methodology

A literature review, field surveys incorporating physical measurements, analysis and synthesis of the collected data is the summary of the methodology which was employed in carrying out this study. The field investigations were aimed at obtaining the first hand experiences of miners working calcium carbonate source rocks in Zimbabwe. It was hoped this would allow the researchers to base their recommendations on field evidence.

Field work also involved discussions with lime producers using unstructured questions with a focus on production levels, technologies in use during mining, crushing, grinding (milling) and analysis of the different process routes being used by the different lime producers in Zimbabwe. During the study, visits were made to the following lime production plants : Kokwe calcite mine owned by F M Mpofu in Matabeleland; Alaska Dolomite in Chinhoyi; Whitelux mine and Yamurai Co-operative in Chinhoyi, Chegutu Stone in Chegutu and owned by G & W Industrial Minerals; Centre West Limeworks in Chimanimani owned by A. Guhu; Nzowe Limeworks in Chimanimani and owned by Zvaidakushinga Co-operative ; D Klerk Limeworks in Odzi and Kadyamusekwa limeworks in Hwange.

Visits were also made to several equipment manufacturers and suppliers in Zimbabwe, whilst suppliers in Zambia were contacted by phone. This was aimed at obtaining information on local availability of equipment suppliers and costs for such equipment.

Terms of Reference For the Study

This study was guided by the aims and methodology outlined by the British Geological Survey (BGS). The suggested work plan is outlined below.

Aim

To identify a small-scale limestone extraction and grinding process route suitable for the low cost production of agricultural lime in Zambia (and other countries in the Southern African/ SADC region).

Methodology

To carry out a desk study to determine the most appropriate methods for small-scale agricultural lime production. Zambia being used as the country focus. The following elements were to be considered.

Agrilime production/Peter & Alfred/5/97

Extraction

Including bush clearance, top soil/overburden removal and open-pit extraction (investigations to consider contractor drilling and blasting as well as manual methods). The extracted stone size was to be less than 500mm.

Crushing

Primary crushing and size reduction of limestone. Work was supposed to consider manual methods to be used to produce crushed stone sizes of less than 20mm.

Grinding

Grinding of limestone to produce final product. Use of manual methods were to be considered. Ground stone should ideally be 100% less than 2mm and 40% less than 0.4mm.

Process Route

A design of the most cost effective process route incorporating recommendations made for extraction, crushing, and grinding. This was supposed to include details of operation, management practice and production costs.

Notes to the Terms of Reference

The study was expected to consider the following points:

- The process should aim to produce low cost agrilime using appropriate technology where possible.

- Production should aim at approximately 0.5 to 1 tonne per day.

- Each element to incorporate manual methods / equipment in preference to mechanical methods (where this does not drastically compromise production).

- Labour/manpower should be considered abundant.

- Appropriate suppliers of equipment in Zambia should be included together with costs (including delivery and installation) and quotes.

- Study to take into account the finance available for ultimate purchase of production equipment for 1997/98 financial year which is 3000 British pounds.

3.0 GEOLOGICAL ASPECTS

Agricultural lime source rocks are limestone, dolostone, marble and calc tufa . Depending on the lithological set-up the carbonate source rocks can form low lands or they can form hills. Dolostone for instance due to its high magnesium carbonate content is not readily soluble in water and can form hills if the surrounding lithologies are weak sedimentary rocks that can be weathered at a faster rate.

The lime source rocks have different physical and chemical properties which have a great bearing on how the rocks occur in nature and how they are extracted and exploited to produce agricultural lime.

Limestone is a sedimentary rock which is composed predominantly of calcium carbonate and in its pure form has a white colour. Some impurities such as iron oxides, chlorite, and clay are normally associated with limestone to give it different colours or shades. Marble is metamorphosed limestone.

Dolostone is also a carbonate sedimentary rock, but it has relatively high amounts of magnesium carbonate. Pure dolostone has 45.72% of magnesium carbonate and 54.27% of calcium carbonate. Impure limestones can have variable amounts of dolomite, in which case they are referred to as dolomitic limestones.

Calc Tufa is a calcium carbonate rock that is formed from the precipitation of calcium carbonate from a calcium bicarbonate solution. In nature calc-tufa is normally white or greyish in colour, porous, soft and friable.

The chemical specifications for agricultural lime are generally not rigid, such that most carbonate rocks can be used to make agricultural lime. Therefore quality aspects are not stringent as regards agricultural lime except for few special cases.
Lime is used to neutralize soil acidity, to supply calcium and magnesium as plant nutrients, improve the crumb structure of soils, to stimulate growth of micro-organisms that help fixation of atmospheric nitrogen into the soil, to liberate potash from clays , to improve soils such that they can retain nutrients and to promote effective use of added fertilizers. Some plants such as tobacco require good amounts of magnesium and in cases where the soils are deficient in magnesium, dolostone will be best suited to the needs of farmers. However the world trend in tobacco markets seems to favour a lighter leaf which is produced by using calcitic limestone rather than dolomite which produces a darker leaf. Dolomite in Southern Africa is used in sandy soils which are generally deficient in magnesium content and calcitic limestone is used in red soils with high magnesium content. Levels of lead in agricultural lime should also be low for coffee, otherwise the lime applied will have negative effects on crop yields.

Crushed limestone, dolomite, chalk, etc are preferred materials by farmers as they are slow acting compared to quick or hydrated lime and hence long lasting. Residual effects of crushed stone are felt some years after application. It must be appreciated that burnt lime in the form of quick or hydrated lime is more reactive and therefore ideal for immediate or short term results.

4.0 PRODUCTION PROCESS OF AGRICULTURAL LIME

There are basically three distinct process routes in the production of agricultural lime. The predominant factors affecting the choice of route are to do with the geology of the deposit, availability of equipment and the cost of the production.

PROCESS ROUTE FOR FRAIBLE MATERIAL LIKE CALC TUFA(1)

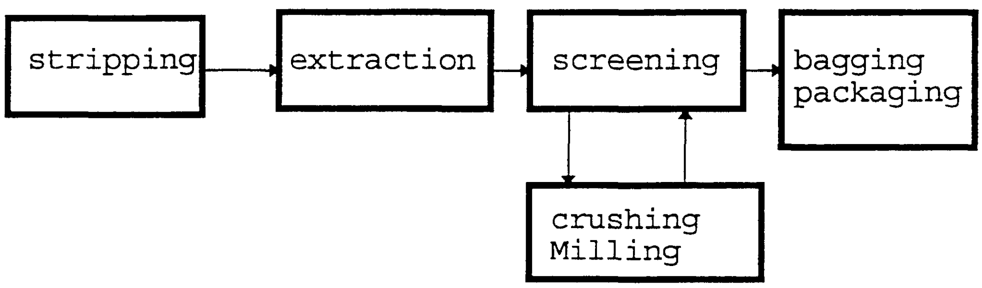


Figure 1

PROCESS ROUTE FOR RELATIVELY HARD ROCK (2) (limestone/dolomite)

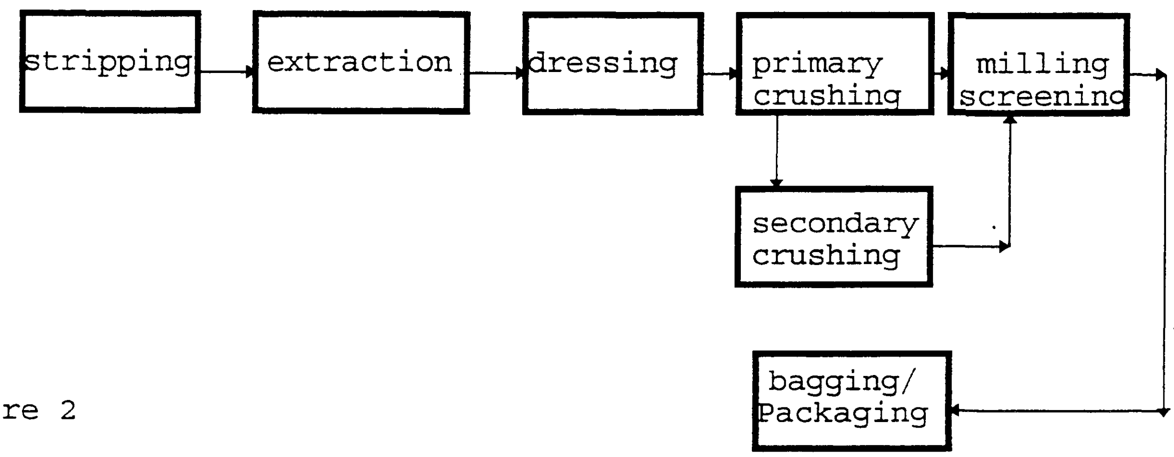


Figure 2

PROCESS ROUTE FOR BURNT AGRICULTURAL LIME(3)

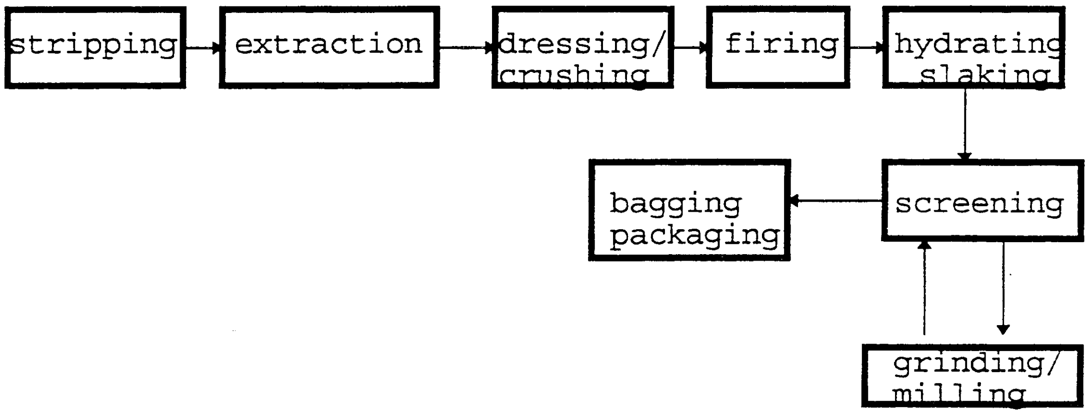


Figure 3

OPERATIONS INVOLVED IN THE PRODUCTION OF AGRICULTURAL LIME

REMOVAL OF OVERBURDEN(STRIPPING)

The thickness and hardness of the overburden and the corresponding cost of removing it, are the most important factors in determining which method to employ. In cases where the carbonate source rocks have formed hills, there will usually be a thin overburden. Trees and shrubs on the hills can be chopped using axes, and cleared away using human labour. The relatively loose and thin overburden is normally removed using picks, chisels ,shovels and wheelbarrows. Use of a bulldozer/ripper may be employed where resources are available and where the overburden is thick and hard to remove manually. The use of a bulldozer/ripper by small scale lime producers to remove overburden can be a cost effective option in terms of productivity.

If the overburden is thick consisting of solid rock and/or soil a bulldozer is needed. The amount of overburden that can be cleared per day (eight working hours) by the bulldozer is a function of type and nature of the overburden, size or horse power of the bulldozer, experience of the operator and gradient of the site where work is being done. Soil is relatively easier to remove than an overburden of overlying rock. It is not easy to work on steep slopes using a bulldozer, and experience of the bulldozer operator is critical.

EXTRACTION/QUARRYING

Mining of calcium carbonate rocks is usually carried out using the open cast method, which is less expensive compared to underground mining. This is mainly caused by the nature of most deposits which are massive and exposed over wide areas. The methods used in quarrying depends largely on the nature of the material. The softer type of limestone could be extracted by means of chisels, wedges, picks, crowbars and shovels with or

Hydration of lime

Quick lime produced from the kiln is very reactive or unstable.

Addition of water to the burnt limestone will produce a stable or less reactive (in terms of handling) hydrated or slaked lime which breaks easily into powder. Hydrated lime contains about 25-30% water. Hydration of lime can be done manually using watering cans and a level platform. However, use of mechanical vibrators have been employed in some cases where production levels are high and where quality requirements are more stringent. After hydration the material like in other processes is screened and then bagged.

rock terrazzo to break them into fine powder. The powder will then be sucked from the ball mill ready for bagging using a pump.

The ball mill can either be driven by a diesel engine or an electric motor where electricity is available.

Use of grinding/hammer mills

Hammer mills with either diesel engine or electric motors as prime movers have successfully been used by small scale lime producers in the production of agricultural lime, particularly from soft deposits like calc tufa. The use of hammer mills to produce agrilime from hard materials such as marble or dolomite would require the use of high resistant manganese beaters to operate for reasonable periods without replacing the beaters and attendant numerous stoppages.

SCREENING

In the majority of the cases a ball mill or hammer mill will have an inbuilt screen with closed circuit to recycle coarse material. In cases where there is need to screen the material after grinding the following screening equipment has been employed:

Standing screens
Rotating barrel screens
vibrating screens.
Grading of the produced lime will depend on the fineness of the screened material . In some operations classifiers with cyclones are incorporated at the screening stage.

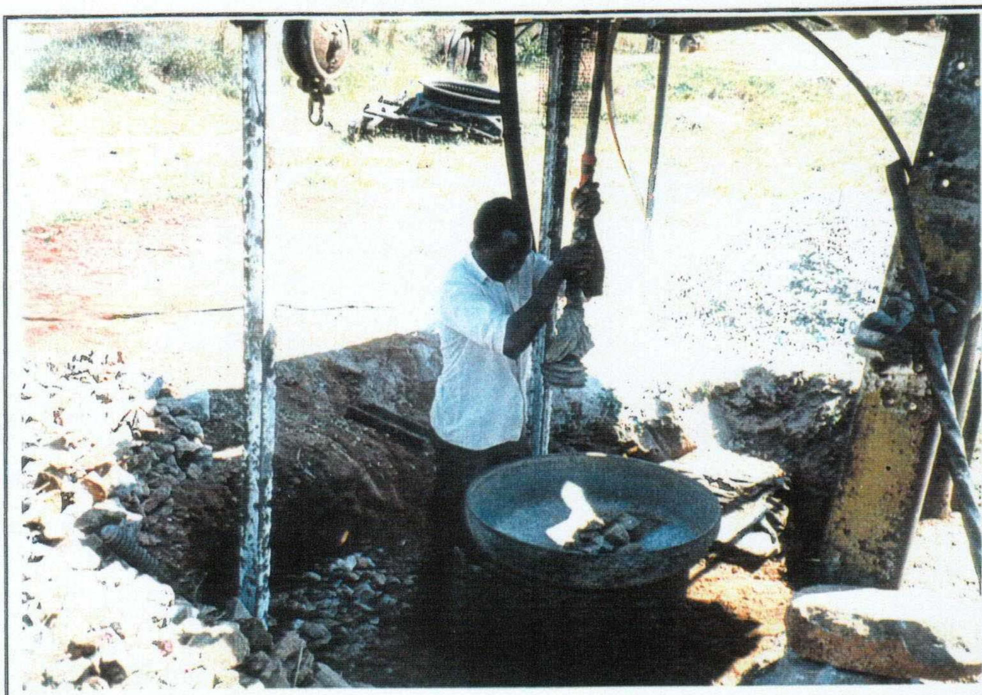
Screening calc tufa at Centre West (Pvt)Ltd

5.0 CRUSHING

Size reduction of limestone, marble or dolostone to less than twenty millimetres can be done manually using rudimentary equipment such as a hammer and a metal base. Such methods are however labour intensive and it will take one person about four days to produce one metre cubic of twenty millimetres (20mm) rock terrazzo, which is equivalent to about 2.7 tonnes of stone.

In some cases hammer mills have been used for this operation but with huge running expenses being incurred on replacing beaters.

A jaw crusher or system of jaw crushers and screens can be used to produce the less than 20mm crushed stone sizes. Normally we have both primary and secondary crushing where two or three jaw crushers with different stone size settings are connected in sequence by means of conveyor belts.



Manual stone crushing at Yamurai in Chinhoyi

6.0 GRINDING/MILLING

Grinding of limestone to produce powder can be done in a number of ways. The various methods are discussed below.

Use of Ball Mills

Stone produced by the jaw crushers can be fed into a ball mill. A ball mill uses steel balls as the crushing media in a steel container that is rotated. As the ball mill rotates at a pre-determined speed the balls fall and collide with the limestone dolomite, however, would require blasting and a great deal of effort if only manual methods are employed. When mining calc tufa deposits picks and shovels may form the main types of equipment for mining because calc tufa is soft and friable. Iron rods can manually be used to make holes into the calc tufa for explosives. Use of explosives will in many cases blow the calc tufa into powder, in some cases the calc tufa will be very friable such that light blasting or no use of explosives will be required at all. Mining of limestone, dolostone and marble can be done manually breaking the rock(s) using a hammer or using fire and quenching with water. Manual methods are however slow and the expenses in labour may be high especially for marble which can be very hard. In such cases it is normal to use drilling and blasting. A compressor, jack hammers and drill steels will be required to make holes into the rock where explosives will be inserted for blasting. Drilling done using one compressor in one day can produce ore that would take three months for five people to produce, if hammers are used to break the rock. Blasting can be done once but in some cases depending on the expertise of blasting personnel there might be need for both primary and secondary blasting.

DRESSING

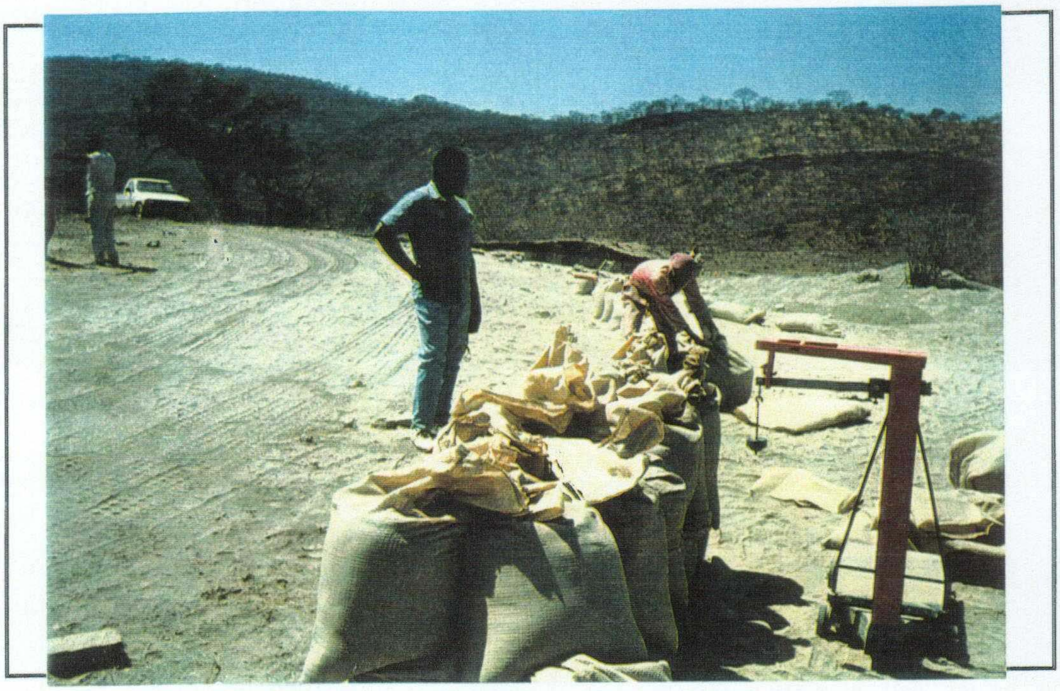
This is basically preparation of quarried stone for the next operation which is normally size reduction of the large stones (500mm) to manageable or appropriate sizes(200-30mm) for the ensuing operation(crushing, firing, etc).

Dressing of quarried stone is normally carried out manually using hammers. At this process stage the stone is reduced to an appropriate size(200-30mm) depending on the requirements of the next operations. More often than not calc tufa will not require dressing.

Stone dressing at Chegutu in Zimbabwe

BAGGING/PACKAGING

Bagging or packaging can be done manually with the help of platform scales. In cases where production levels are high the use of semi-automatic packaging equipment has been employed, material from the ball mill being channelled directly to the packaging equipment with the use of suction pumps.



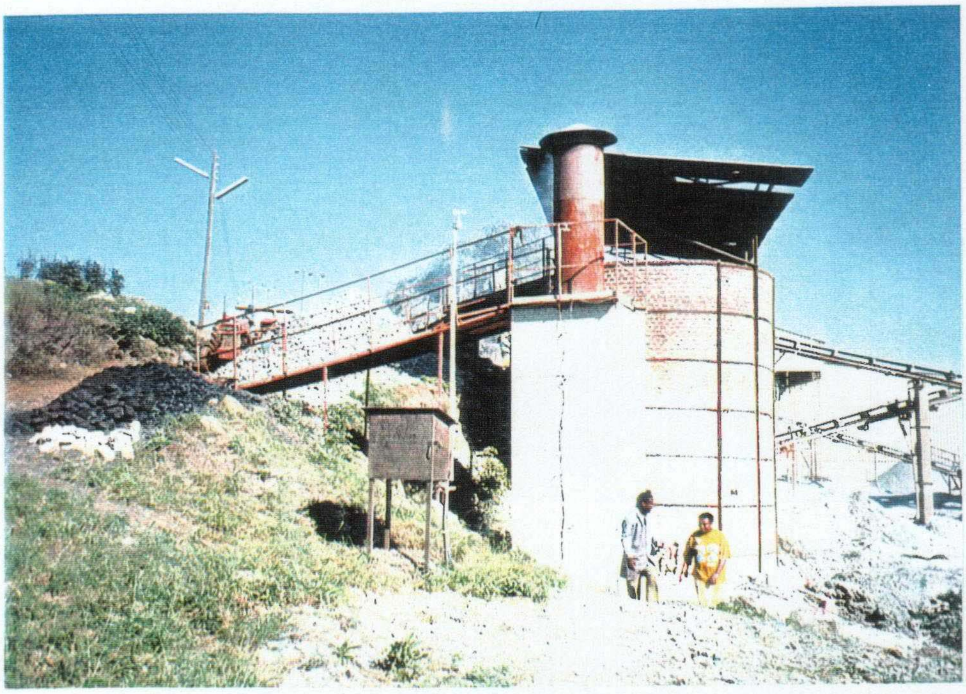
PRODUCTION OF BURNT LIME

From the flow chart diagram for the production of burnt lime it is evident there are two distinct process stages unique to this product, that is the firing stage and the hydration stage.

Firing of dressed stone.

Firing of quarried stone which has been reduced to 200-30mm, can be done using the traditional heap burning method ,box kilns, pot kilns or more efficiently using the continuous vertical shaft kiln. The heap burning and the pot kiln methods are both batch or intermittent processes where waste heat is not utilized. In the heap burning and box kiln methods the dressed stone and fuel are interspaced in layers forming a heap. In the pot kiln method fuel is burnt at the bottom to calcine the stone which is piled in the kiln.

In the vertical shaft kiln the fuel and stone are fed alternately into the kiln. Waste heat is used to preheat the mixed feed while calcined material(quick lime) going out towards the discharge gate is used to preheat incoming air. The heat treatment or calcination will liberate carbon dioxide from the limestone to produce calcium oxide. Various types of fuel are used in the production of quick lime. The following fuel types have been used in Southern Africa: wood, charcoal, coal and oil.

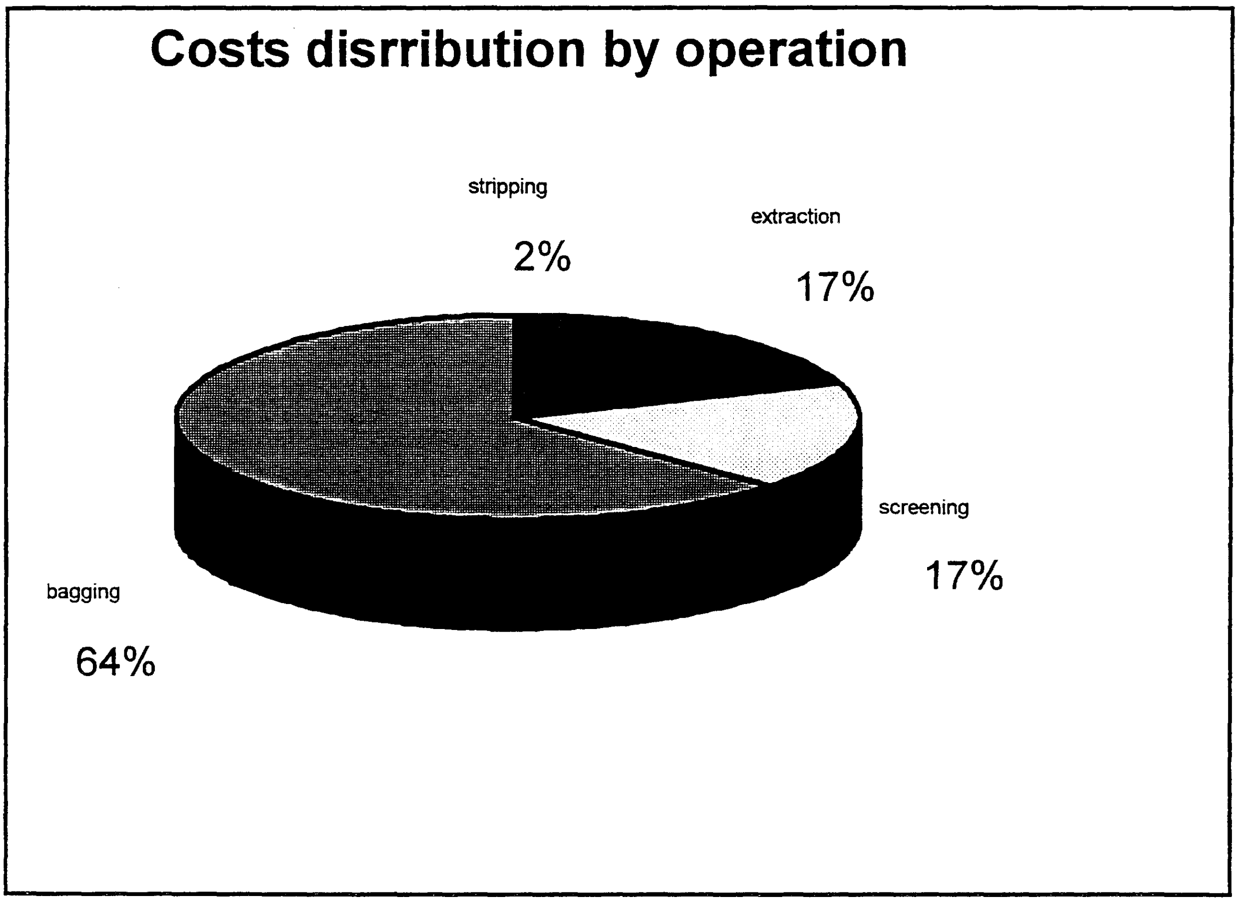


Vertical shaft kiln firing at Chegutu

Heap burning in Chimanimani

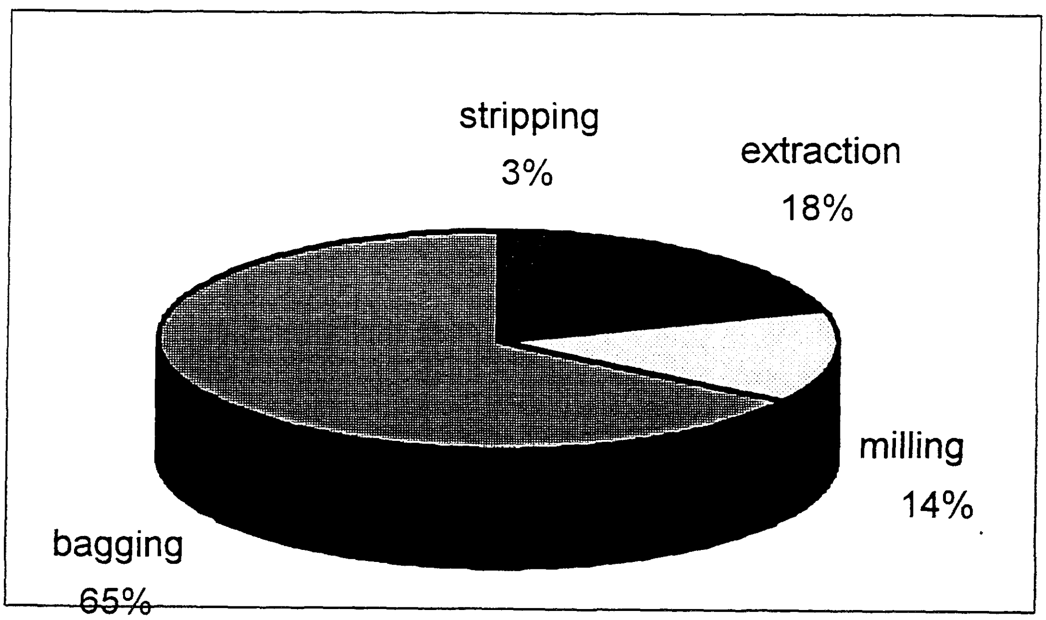
7.0 PRODUCTION COST OF AGRILIME

Approximate production of one tonne of calc tufa according to process route (1a)					
It is assumed that manual operations are employed throughout.					
Operation	**direct costs**	**Depreciation & Maintenance**	**Total costs**		
	US$/T	US$/T	US$/T		
Stripping	0.116	0.011	0.127		
Extraction	0.83	0.071	0.901		
Screening	0.83	0.075	0.905		
Bagging	3.21	0.125	3.335		
SubTotal			**5.268**		
Overheads			0.5268		
Total			**5.7948**		



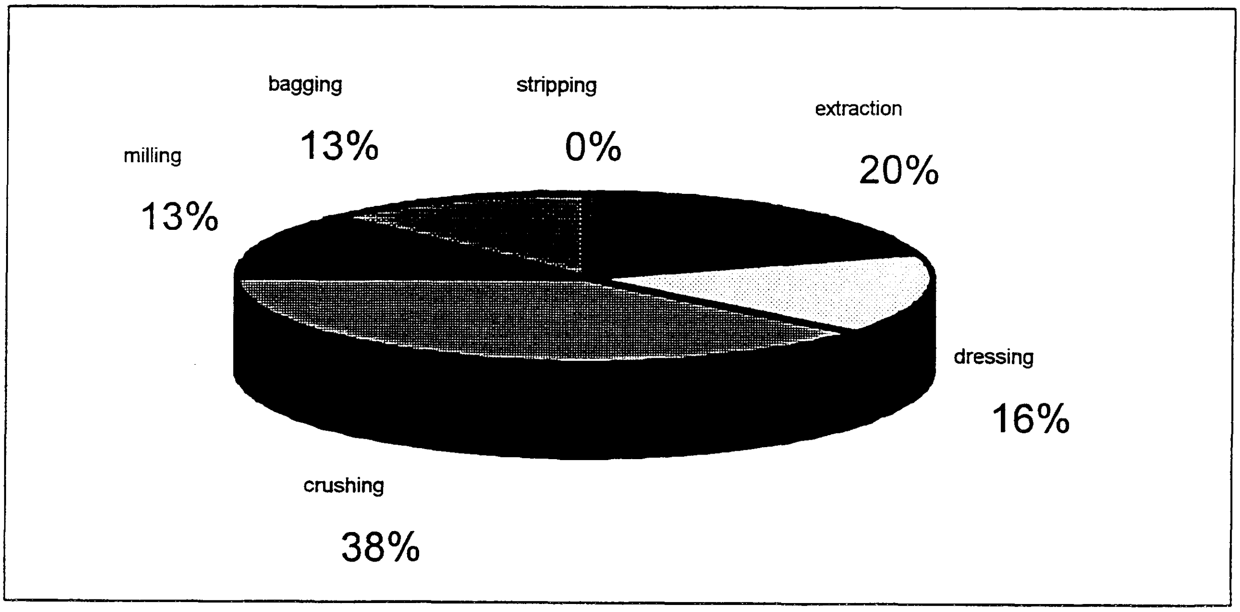
Process Route(1b) with hammer milling and a cyclone				
Operation	**Direct costs US$/T**	**depreciation & Maintenance US$/T**	**Total costs US$/T**	
Stripping	0.116	0.011	0.127	
Extraction	0.83	0.071	0.901	
Milling	0.53	0.167	0.697	
Bagging	3.21	0.125	3.335	
Sub Total			**5.06**	
Overheads			0.506	
Total			**5.566**	

Costs distribution by operation

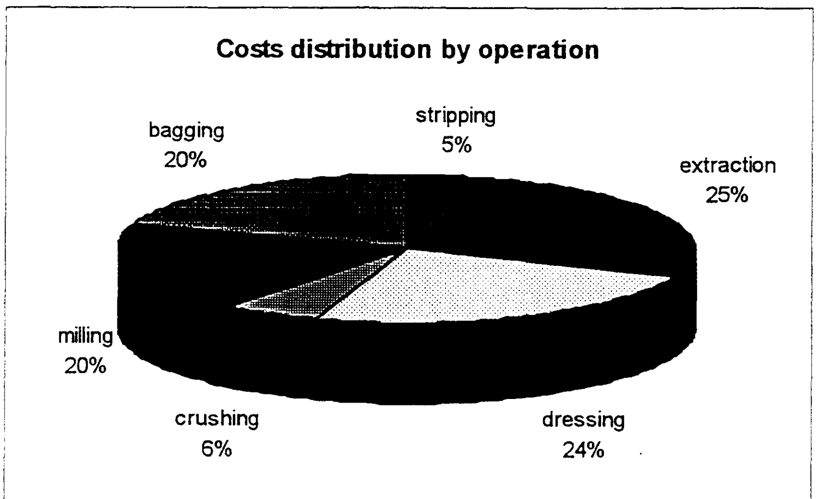


Approximate cost of production of one tonne according to process route 2a				
It is assumed that manual methods are employed throughout except for the milling operation.				
Operation	**Direct costs US$/T**	**Depreciation & Maintenance US$/T**	**Total Costs US$/T**	
Stripping	0.116	0.011	0.127	
Extraction	5	0.22	5.22	
Dressing	3.75	0.36	4.11	
Crushing	10	0.24	10.24	
Milling	1.65	1.67	3.32	
Bagging	3.21	0.125	3.335	
SubTotal			26.352	
Overheads 10%			2.6352	
Grand Total			**28.9872**	

Costs distribution by operation

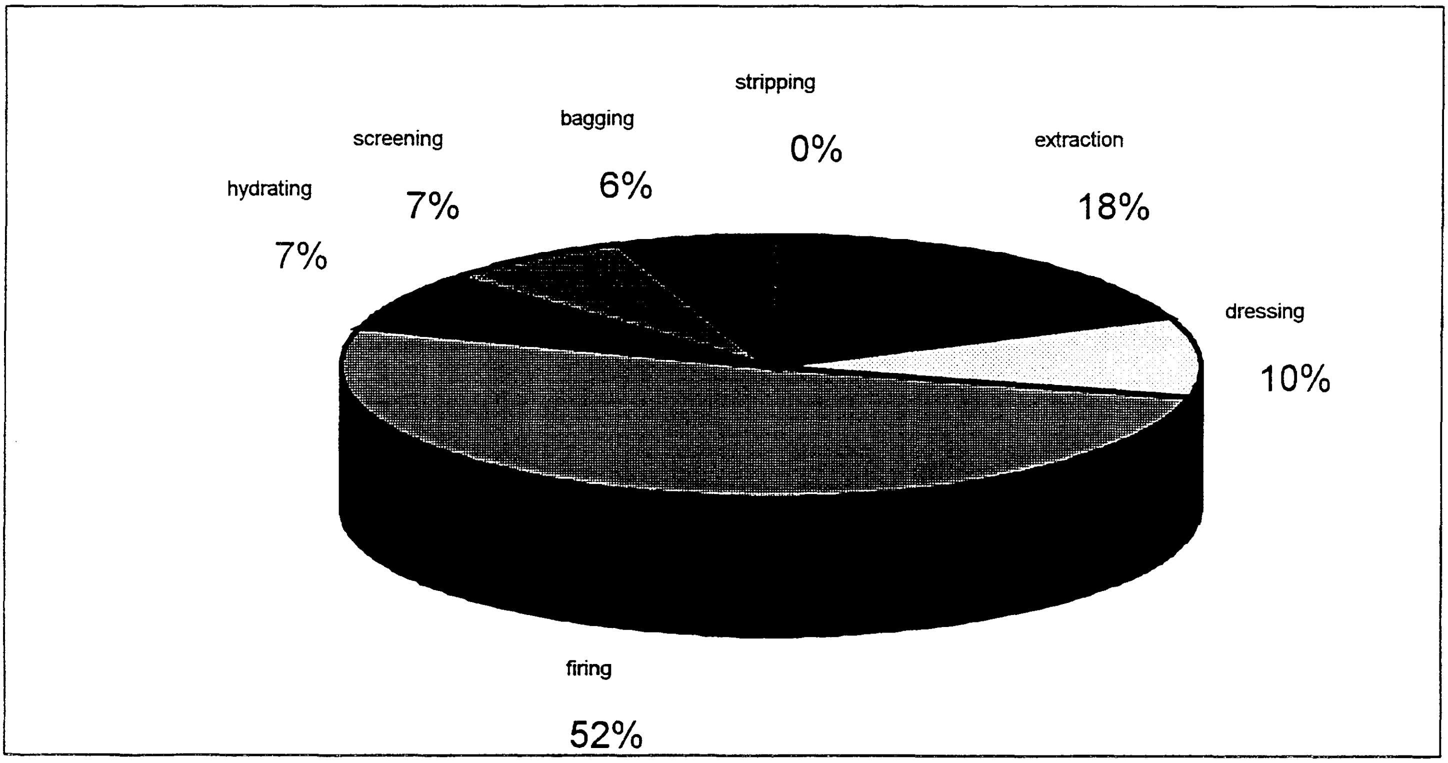


Approximate production cost of one tonne of lime according to process route 2b				
It is assumed that hired equipment is used for stripping and extraction, and crushing is mechanised.				
Operation	**Direct costs US$/T**	**Depreciation & Maintenance US$/T**	**Total Costs US$/T**	
stripping	0.85	0	0.85	
Extraction	4.36	0	4.36	
Dressing	3.75	0.36	4.11	
Crushing	0.44	0.5	0.94	
Milling	1.65	1.67	3.32	
Bagging	3.21	0.125	3.335	
Subtotal			16.915	
Overheads 10%			1.6915	
Grand Total			**18.6065**	

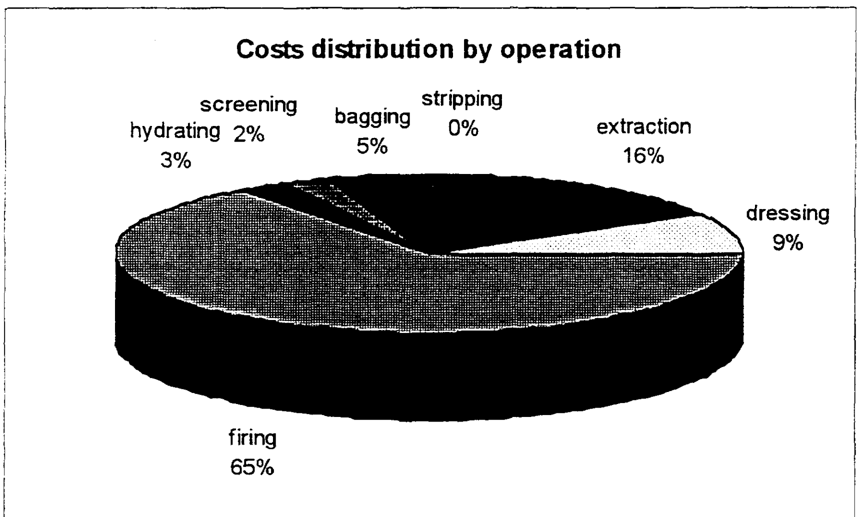


Approximate production costs for one tonne of burnt lime according to process route 3a				
It is assumed operations are basically manual and a vertical shaft kiln is employed				
Operation	**Direct costs US$/T**	**Depreciation & Maintenance US$/T**	**Total costs US$/T**	
Stripping	0.232	0.022	0.254	
Extraction	10	0.44	10.44	
Dressing	5	0.48	5.48	
Firing	27.5	1.3	28.8	
Hydrating	3.65	0.475	4.125	
Screening	3.65	0.35	4	
Bagging	3.21	0.125	3.335	
Sub total			56.434	
Overheads 10%			5.6434	
Gr.Total			**62.0774**	

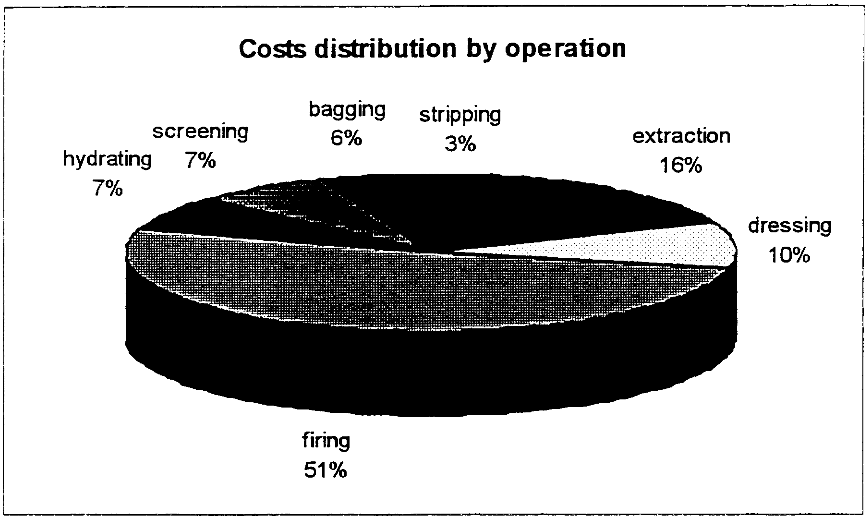
Costs distribution by operation



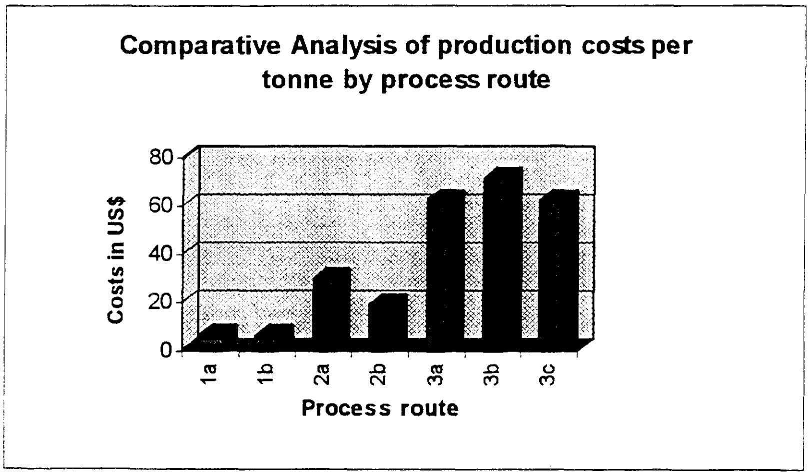
Approximate production costs for one tonne of burnt lime according to process route 3				
It is assumed operations are basically manual and a traditional kiln is employed for firing the stone.				
Operation	**Direct costs US$/T**	**Depreciation & Maintenance US$/T**	**Total costs US$/T**	
Stripping	0.232	0.022	0.254	
Extraction	10	0.44	10.44	
Dressing	5	0.48	5.48	
Firing	41.2	0.167	41.367	
Hydrating	1.25	0.475	1.725	
Screening	1.25	0.35	1.6	
Bagging	3.21	0.125	3.335	
Sub total			64.201	
Overheads 10%			6.4201	
Gr.Total			**70.6211**	



Approximate production costs for one tonne of burnt lime according to process route 3				
It is assumed that hired equipment is used for stripping and extraction and a vertical shaft kiln is employed				
Operation	**Direct costs**	**Depreciation&Maintenance**	**Total costs**	
Stripping	1.7	0	1.7	
Extraction	8.72	0	8.72	
Dressing	5	0.48	5.48	
Firing	27.5	1.3	28.8	
Hydrating	3.65	0.475	4.125	
Screening	3.65	0.35	4	
Bagging	3.21	0.125	3.335	
Sub total			56.16	
Overheads			5.616	
Gr.Total			**61.776**	



Comparative Analysis of production costs by process routes			
per tonne of agrilime			
Process route		Production costs of one tonne	
			Costs in US$/T
1a	5.8		5.8
1b	5.57		5.57
2a	28.98		28.98
2b	18.61		18.61
3a	62.08		62.08
3b	70.62		70.62
3c	61.78		61.78



Prevailing Market prices of Agrilime

It might be necessary here to emphasize the fact that it is normally the milled raw carbonate not the burnt product which is used for agricultural purposes. Burnt lime is generally used for building purposes, mineral processing, water purification etc.

The current selling price for screened calc tufa or milled raw carbonate range from Z$300.00(US$30.00) to Z$433.00(US$43.30)per tonne. The prevailing prices for hydrated lime range from Z$913.00(US$91.30)to Z$1588.00(US$158.80) per tonne.

8.0 CALCULATING COST OF PRODUCTION PER TONNE

Stripping

Stripping is defined for the purposes of this research work as the removal of overburden material only, which will allow the extraction of limestone on a mining site.

Assumptions

That the overburden consists of soil, loose and weak rock that can be removed easily.

The depth (thickness) of the overburden material is one metre.

If 200 tonnes of limestone is to be extracted to a depth of 1.5metres then the area occupied by this deposit would be 200/(1.5x2.7) or 49.38m^2 , where 2.7 is the density of the ore in tonnes per cubic metre.

It is assumed ground conditions can allow use of human labour, and or graders, dozers and rippers.
If human labour is used it is assumed five people will be able to remove and dump away four cubic metres of overburden material (including cutting down trees and shrubs) per day, exposing at least four square metres of ground to allow limestone mining.
A dozer, grader or ripper is assumed to be able to clear at least forty square metres of one metre thick overburden per day to pave way for limestone extraction.

That the deposit(s) is accessible.
That there are 200 working days per annum.

Manual / Use of Labourers

If human labour is used to strip an area before extraction commences. Tools which will most likely be used include:

Axes

Picks

These will be used to dig, and loosen the soil and other overburden material before it is loaded into wheel barrows and disposed off.

Shovels

Necessary for use when loading wheel barrows.

Wheel barrows

To be used to ferry overburden material away from the site of works to a dumping ground.

Hammers

May be necessary to break large chunks of rock, so that it is easy to remove them.

It is estimated that five people are required to strip a forty metre square area with overburden which is one metre thick over a period of ten days. Three axes, three picks, three shovels, two wheel barrows and three hammers will need to be purchased for use by workers. All the equipment is expected to have a life of one year.

Stripping will initially need to be done for an area of at least forty square metres before extraction of limestone commences to allow for pit planning and design. If for instance compressors and jack hammers are going to be used it will be economic to have a bigger area exposed for drilling and blasting so that at any time a hired compressor is used effectively. It will not make economic sense if a little area is exposed for drilling such that only a few drill holes can be produced at a time.

Labour costs

To remove overburden over an area of forty square metres. It will require 5 x 1 x 10 days = 50 man working days.
Each worker will be paid US$2.5 per day. Labour cost will therefore be $2.5 x 50 = US$125.

Tools costs

Tools and the associated costs which will be required are summarised in table 1a.

Table 1a showing the type and cost of equipment which can be used by ten people when stripping overburden material.

EXTRACTION

Extraction is used in this context to refer to the actual mining, digging out of ore, or removal of ore from the ground. It includes such processes as drilling and blasting. In this process human labour with simple rudimentary tools can be used, or alternatively jack hammers powered by compressed air and explosives can be used.

Assumptions

That there will be 200 working days per year excluding public holidays, sundays and stoppages due to bad weather.
That each worker will be paid $2.5 per day.

That picks, hammers and crowbars will have a lifespan of one year.

Four workers can produce two tonnes per day, using picks, hammers and crowbars.

Manual / Use of Labourers

Field work carried out revealed that on average a miner (worker) can extract one tonne of limestone per two working days. The limestone will have sizes ranging from 500mm to 200mm. To mine one tonne of limestone per day will therefore require a labour force of two miners (labourers) each day.

Tools commonly used by labourers include fourteen pounds hammers ,picks and crowbars. Two workers on a mine would require two hammers, two picks and two crowbars.

Costs

Labour costs

Two workers at US$2.5 for 200days = 2 x $2.5 x 200 = $1000.00

Equipment

Two hammers at $7 = $14.00
Two picks at $10 = $20.00
Two crowbars $5 = $10.00

Total extraction cost would be $44.00 plus $1000.00, giving US$1044.00

Since there are 200 working days and extraction is at a rate of one tonne per day. Cost of extracting one tonne of limestone would be US$1044.00/200, giving US$5.22 per tonne.

Use of Drilling and Blasting

Assumptions

That one compressor and jack hammer will be hired out at any one time at a cost ofUS$250.00.

That drill holes will be made to a depth of 1.5m.
That at any one day when drilling is done an area of twenty metre squares will be drilled for blasting to a depth of 1.5m yielding ***eighty one*** tonnes of limestone ore.
That the explosives to be used to yield thirty tonnes of limestone will have a total cost of $15.00
Hiring the drilling and blasting service including labour will be $250.00 per day.

Cost of Drilling and Blasting

Production is targeted at one tonne per day. If there are 200 working days per year, annual production will therefore be 200T. A compressor and a jack hammer will therefore be hired three times a year to meet the production target of one tonne per day.

Drilling costs = 3 x $250 = $750.00
Explosives expenses = 8.1 x $15 = $121.50
Labour is included in the drilling costs.
Total = $871.50

Therefore 243 tonnes will be produced per annum at a cost of US$871.50, giving US$4.36 per tonne.

DRESSING

Assumptions

One person will be hired to remove one tonne of blasted ore for dressing for half a day.

One person will be employed to dress the one tonne of ore per day.

Costs of dressing:

Labour costs:

Cost of labour would be 1.5man-days x US$2.5/tonne, giving US$3.75 per tonne.

Depreciation costs on tools

One wheelbarrow	@	US$65.00
One Hammer	@	US$7.00
Total costs		US$72.00

Therefore costs of depreciation of tools per tonne would be US$72.00/200, giving US$0.36/tonne.

Hence cost of dressing per tonne would US$4.11

CRUSHING

Crushing is used in this context to refer to break down of rocks into small rock terrazzo of less than 20mm.

Use of Labourers

Again human labour can be used, with simple tools. On average an individual worker can produce one tonne of ore using a hammer and a metal base plate to crush 500mm rock sizes to 20mm stones over a period of four days.

To produce one tonne per day of 20mm rock terrazzo would require four labourers. If each worker is paid US$2.5 per day. The human labour cost per day would be 4 x $2.5, giving US$10.00/tonne. If there are 200 working days the total labour cost per annum would be 200 x $10, giving $2000.00.

Cost of tools

4x 10 Pounds hammers @ $7 each = $28.00
4 Base plates @ $5 each = $20.00
Total cost/annum = $48.00

Total cost of using manual methods would be US$2048.00.

Therefore cost of one tonne crushed stone will be US$10.24.

Use of Jaw Crusher(s)

Assumptions

That a three tonne per hour jaw crusher can consume fifteen litres of diesel per day (8 hours).
That there are 200 working days per annum.
That life of ajaw crusher will be ten years.
Price of diesel is $0.5 per litre.
That electricity from the main national grid will not be used.
The cost of maintenance per annum would be 10% of purchase price.
One operator is required to man the crusher.

Costs

Jaw or cone crushers can be used to reduce the size of rocks from 200mm to less than 20mm. Jaw crushers are faster compared to use of labourers, and would suit an operation where production is much higher compared to one tonne per day. In most SADC countries jaw and cone crushers are imported from Europe, Australia or America and are quite expensive.

Quotations obtained during the study, revealed that jaw crushers which can do three tonnes per hour cost about US$12 000.00. Five tonne per hour jaw crushers cost about $30 000. Cone crushers are much more expensive at about $80 000. The quotations include the machine, V-drive, diesel engine, and a machine base .

Costs of depreciation

If a three tonne per hour jaw crusher were to be bought with an expected life of ten years. Over the ten years it would be able to crush 48000 tonnes of limestone . Therefore depreciation costs of a jaw crusher unit per tonne would be $12 000.00/48000 , giving $0.25 per tonne.

Costs of fuel

Fuel consumption will be 15 litres per day at a cost of $0.5 per litre. If about 24 tonnes are crushed using 15 litres the cost of fuel per tonne will be $0.31.

Cost of maintenance

Maintenance costs per tonne would be US$0.10x12 000.00/4800, giving US$0.25/tonne

Labour costs

The operator is paid US$3.2 per 8-hour shift day.

Hence labour costs per tonne using a jaw crusher would be US$0.13.

Total crushing costs using a jaw crusher would be US$0.94/tonne

MILLING

Milling of limestone can be done using ball mills, with suction pumps, electric motors and ancillary equipment. Use of ball mills normally require installation of a diesel engine or electricity which can be very expensive for remote areas. The cost of purchasing ball mill unit runs into several tens of thousand of dollars. Dry ball mill units for lime production are normally imported from developed countries, and are associated with medium to large scale production of lime. However some companies in Zimbabwe are producing units which can produce up to one tonne per hour, which would be ideal for small scale operations.

Installation and purchase of a one tonne per hour dry ball mill unit cost $20 000. If the ball mill has a life of ten years, and milling is done twenty four hours per day, such that at least twenty four tonnes are milled per day. Over ten years about 48 000 tonnes will be milled.

Assumptions

Cost of operator is US$3.2 per 8hr shift.
Consumption of fuel is 20 litres per 8hr shift.
Maintenance cost is about 10% of purchase price.
The milling unit is expected to last 10 years and depreciation is calculated on a straight line basis.

Cost of milling

Using the same arguments as in the crushing case, the costs of milling one tonne is calculated to be about US$3.32

BAGGING

Assumptions

It is assumed that one person can package at least twelve tonnes per day and that the cost of packaging is US$3.0/tonne

Cost of labour is US$2.5 per day.
Direct costs on bagging per tonne would be US$3.21

COSTS OF PRODUCING BURNT LIME

The stripping, and crushing aspects discussed in the previous section would also apply when producing burnt lime from limestone using kilns and will not be discussed or repeated under this section. The use of vertical kilns is discussed below.

Assumptions

That the kiln will have a life of at least twenty five years.
Maintenance costs will be 2.5% of original construction cost of the kiln.
Depreciation will be calculated on a straight line basis.
That there are 200 working days per year.
That every 2 tonnes of limestone burnt will yield 1 tonne of quicklime which will be hydrated. The yield in terms of hydrated lime will about 1.3 tonnes per day.
That the firing and conditions in the kiln will burn the limestone such that after hydration the quicklime will disintegrate easily, such that there will be virtually little or no mechanical crushing.
The fuel to stone ratio is about 1:5 .
The output per day of the kiln is one tonne of quicklime.
The costs of the kiln is US$4000.00, however it is potentially possible to construct the kiln at a lower cost.

One operator would responsible for feeding and discharging the kiln.

Another operator would be responsible for and hydrating ,screening and bagging the quicklime.

Depreciation costs

If the kiln is assumed to have a life of twenty five years, a total of 5000T of quicklime will be produced over this period. Depreciation costs of the kiln per tonne of quicklime produced will therefore be $4000.00/5000, giving $0.8per tonne. All tools are believed to have a life of one year.

Fuel Cost

A tonne of coal or any solid fuel such as charcoal which can be used in the kiln is estimated to cost $60 per tonne delivered. About 0.4T of coal is consumed when burning of 2T of limestone to produce one tonne of quicklime. For every tonne of quicklime produced 0.4 x $50.00 = $20.00 is spent on fuel alone. Cost of fuel using the traditional kiln is relatively higher than using the vertical shaft kiln.

Labour cost

Two operators per shift are employed to man the kiln and further process and package the product. Hence total labour costs per day will be 2xUS$2.5x3, giving US$15.00/day for firing, hydrating, screening and bagging.

Grinding/milling calc tufa

Production of friable calc tufa for agricultural purposes could be done using hammer mills with diesel engines as prime movers. The cost of such a milling unit would be about US$5000.00.

USE OF OTHER APPROPRIATE EQUIPMENT

Available on the market today are grinding mills/hammer mills with high resistant beaters which can reduce dressed stone to powder(25mesh). The unit cost of such an equipment would be US$12000.00 and throughput per day is estimated to be about 8 tonnes . These hammer mills are available from ABJ Engineering in Bulawayo ,Zimbabwe. Performance of these mills in a real production situation has not been adequately evaluated to give reliable information on the expected frequency of replacing beaters as a function of throughput per day. However,it has been estimated that replacement of manganese beaters would required after milling 100 tonnes of limestone. Each set of beaters would cost US$100.00. ***Employing similar arguments as before,and assuming that fuel consumption rate is 12 litres per day, the cost of milling one tonne of lime would be US$2.4.***

ABJ Engineering is also marketing a 1 tonne per hour jaw crusher at a total price of about US$9000.00 including the prime mover. ***Employing the same arguments as before and assuming that fuel consumption rate is 12 litres a day, the cost of crushing one tonne of lime would be US$2.28***

Also available from Clarson and Co (Pvt) Ltd, Harare, Zimbabwe is combined jaw crusher and roller crusher with an output of about 1.5 tonnes per hour at a cost of about US $ 15000.00 with a diesel prime mover. The product is less than 2mm in fineness. The cost of using this equipment employing the same arguments would be as follows:

- Cost of fuel(diesel)per tonne would be$0.5(*consumption rate is assumed to be 12 litres per 8hr shift)*
- Depreciation costs per tonne would be US$0.65
- Maintenance costs per tonne would be US$0.65
- Costs of labour per tonne would be US$0.27

Hence total costs of crushing and milling one tonne would be US$2.02

Also available from Fletcher, Randsburg in South Africa are small ball mills with an output of about 2 tonnes a day at a total cost of US $5200.00 per unit including the prime mover. Therefore the costs of milling one tonne would be as follows:

- Cost of fuel, assuming consumption rate is 5 litres per day, would be US$1.10/tonne
- Depreciation costs per tonne would be US$1.3
- Labour costs per tonne would be US$1.6
- Maintenance costs per tonne would be US$1.3

Total milling costs per tonne would be US$5.3.

9.0 CONCLUSIONS:

From the preceding paragraphs it is evident that the production costs and the type of equipment required for the production of agrilime are largely dependent on the nature of the rock, whether it is soft and friable or hard. A hard material would require more expensive equipment for crushing and milling purposes.

With a budget of about 3000 pounds , it would be feasible to exploit soft and friable stone like calc tufa and perhaps heavily leached limestone. However for hard rock like marble or dolomite the proposed budget would be inadequate.

The operating costs for producing hydrated/slaked lime are quite high, especially that of fuel, making this product uncompetitive for agricultural purposes against milled raw limestone . Despite the foregoing the initial cost of investment of a kiln would be affordable given the budgetary constraints.

Thus finally looking at the worst scenario where we are processing hard rock and from an investment perspective where emphasis would be on labour intensive processes, the optimum process route would be :

- Manual stripping
- Manual extraction
- Manual dressing
- Manual crushing
- Mechanised milling(2tonne mill per day)
- Manual bagging
- ***The production costs per tonne using this route would be US$31.17. Considering the prevailing market prices for this product, a relatively low profit margin would be realised with a long payback period.***

If the aim is to realise a relatively high profit margin which would also yield a short payback period without incurring huge capital investments the following process routes have to be considered:

Option II

- Manual stripping
- Hired extraction
- Manual dressing
- Mechanised crushing and milling(Clarson Co mill)
- Bagging

The total production costs per tonne using this route would be US$15.35.

Option III

- Manual stripping
- Hired extraction
- Manual dressing
- Mechanised crushing and milling(hammer mill)
- Manual bagging

The total production cost per tonne according to this process route would be US$15.76.

It must also be highlighted that from economies of scale 200 tonnes per annum is small figure to break even if the profit margins are low.

APPENDIX 1: EQUIPMENT SUPPLIERS

USE	TYPE OF EQUIPMENT	SUPPLIER(S)
Mining/ Extraction	Picks, shovels, wheelbarrows, hammers, axes, and crow bars.	Hardware shops mostly in urban areas.
	Explosives	Kafironda Ltd, PO Box 40092, Mufulira, Zambia.
	Compressor and Jack Hammers	Ingersoll Rand (Pvt)LTD, Atlas Co-opco.Zambia
	Drill steels	Boart Longyear Ltd, Po Box 71577, Ndola, Zambia
	Drill sharpen-ing unit	"
	Drill bits	"
Crushing Crusher and Mill in One	Jaw Crusher	• Conolly in Zimbabwe, Boart Longyear (Samuel Osborn) in Zambia. • Clarson & Co (Pvt) Ltd P.O.Box 43 Harare, Zimbabwe Tel 754039/40. Fax 754041
	Ore bin	Thita Engineering Services, PO Box 90369, Luanshya, Zambia.
Milling	Ball Mills	Tonks Engineering, Box 1319, Mutare, ABJ Engineering(Pvt) Ltd, P O Box 9203, Byo; IMF Machinery P.O.Box 902 Byo Zimbabwe, Fletcher, P.O.Box 2839, Randsburg 2125, S.Africa Tel No (011) 787 5200 Fax No(011) 787 8623.
	Cone crushers	Imported
	Kilns	Can be made locally
	Hammer mills	Are produced in Zimbabwe, Precision Grinders, Box 1790, Harare, Bells Engineering, Mutare, Tanroy Engineering Box AY382, Amby, Zimbabwe.
Screening	Screens	John Searcy, Hre

APPENDIX 2

CASE STUDIES

CASE STUDY I

Kokwe Mine

The Kokwe mine is a calcite mine which is owned by M F Mpofu of Ntabazinduna. The mine which is 40km from Bulawayo and can be accessed using the Bulawayo-Harare highway. Work on the mine commenced in February 1994.

Geology

The calcite occurs as veins in the country rock which is a meta-basalt. The meta-basalt is tough and difficult to break using a hammer or pick. Most of the calcite is grey and friable as it has been leached. Some of the calcite is however hard, white in colour and crystalline. The calcite claim consists of a number of veins with different strikes and continuity. The calcite is almost pure with very low magnesium, silica, and iron content. The veins and pods of calcite go to depths of four metres.

Mining

Simple opencast mining is used to mine the calcite. Calcite is dug out using a pick and thrown out of the pits created during mining using shovels. During extraction the calcite is carefully removed making sure that it does not mix with the country rock waste material. The friable ore is carefully removed for manual crushing and sieving whilst the hard crystalline calcite is stockpiled.

Crushing of the friable ore is done using the hand, whilst sieving is also done manually using metal sieves. The crushed ore is then packed into plastic bags ready for delivery to the market. The calcite which still requires milling is stockpiled and is sold to companies that have the necessary machinery for milling.

Production

Production at Kokwe mine averages about 32T per month which is rather low, especially considering the number of people employed and also the market price for the calcite. Each tonne of calcite sells at $90, leading a monthly revenue of $2880. The mine owner employs ten casual workers mainly women and young school leavers. Fortunately most of the lime consumers provide their own transport when buying lime from Kokwe mine.

Marketing

The calcite produced is sold to Agrifoods where it is used in poultry products. Other potential buyers are Dunlop who can use the calcite as a filler in rubber, and National Foods who add some of the calcite to common salt. Due to low productivity Kokwe mine can not supply all potential users of the mine's product.

M F Mpofu has not started selling his calcite to farmers, as Matabeleland is basically an extensive cattle ranching area and demand for agricultural lime is low. Peasant farmers in Ntabazinduna do not also know advantages of using lime.

Remarks

It appears lime is a relatively low value product that can be profitable if production is high, and carried out in the most cost effective way.

CASE STUDY II

Production of Agrilime from Calc Tufa at Centre West Mine in Chimanimani.

Nature of deposit

The deposit is friable and soft calc tufa. The reserves are reasonably extensive and about 40million tones of ore is available.

Stripping

Removal of overburden has been done using hired machinery(bulldozer).

Extraction

Is done either manually or by a plough using a tractor.

Screening:

Is done manually using standing screen (2.5mm).

Milling:

Lumps of the friable tufa are milled using a hammer mill which is propelled by tractor engine.

Bagging:

Is done manually using a platform scale.

Agrilime production/Peter & Alfred/5/97

Throughput:

Throughput per day on a manual regime with three screens operating is about 18 tonnes or 6 tones per shift with 15 people.

With the hammer mill output is about 45-51 tonnes per day. Diesel consumption per day is about 25 litres.

Selling Price

The selling price of one tonne of agrilime from Centre West Mine is $300.00 (US$30.00).

Markets:

The product from Centre West Mine is sold mainly to commercial farmers around Chimanimani and Chipinge Districts.

APPENDIX 3

REFERENCES

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BARBER B. 1990.Calcium Carbonate In Zimbabwe. Mineral Resources Series No.21. 1990.

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E.AGEVI, O.RUSKULIS, T.SCHILDERMAN Lime and alternative binders in East Africa.

SECTION F:
THE MILLING OF AGRICULTURAL LIME

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1. INTRODUCTION

This paper is concerned with the grinding of agricultural lime (aglime) using the TD Hammermill which is *designed and manufactured by the Technology Development and Advisory Unit* (TDAU) at the University of Zambia.

The Technology Development and Advisory Unit (TDAU) has been actively participating in the improvement of appropriate technology, mainly in mechanical and manufacturing engineering, since 1975. This was primarily in support of the poorest of the poor but is now targeted at the development of small business and the enterprise culture. The strategy undertaken by the TDAU involves the dissemination of practical technologies applicable for small business that have been redesigned appropriate to Zambian conditions.

The TD Hammermill, shown in Figure F1 (and Plates F1 & F2), was designed from an idea originally conceived by ACEDEM (African Regional Centre for Engineering Design and Manufacturing) in Nigeria and redeveloped at the TDAU for the Zambian environment.

Figure F1. The TD Hammermill.

The *TD Hammermill is unique* in the Zambian market and is the newest and latest hammermill technology to be introduced into Zambia. Originally conceived for milling mealie meal, it's flexible technology is now being applied to the milling of minerals and in this case agricultural inputs such as lime.

The TD Hammermill is designed with the following attributes:

- the mill is portable allowing the miller to move from one site or market to another without losing customers,
- the mill is flexible and can be used for milling mealie meal and feedstock as well as aglime,
- the mill has low maintenance as the hammers are directly driven by the engine, i.e. without the use of expensive bearings and there is no cyclone or belt attachments to increase maintenance costs,
- the mill is driven by a simple petrol engine which can be easily maintained by any mechanic.

Within the competitive market for mealie meal, TD Hammermill *is designed to increase income for a mill owner*. The mill is designed to be portable and flexible so that the owner can compete with other hammermill owners and industrial millers.

2. AIMS

The aim of this work is to develop a method of producing aglime from mined product. This was to be done using hammermill technology traditionally used for the milling of foodstuffs. The aim of this work was to

- determine the ground output using different sieve sizes
- determine the cost of milling at different sieve sizes
- determine the particle size of milled product

3. METHODOLOGY

The TD Hammermill, shown schematically in Figure F2, was set up as for normal milling of mealie meal. The unit consists of 12 hardened steel hammers directly driven by a Briggs and Stratton 8hp petrol engine.

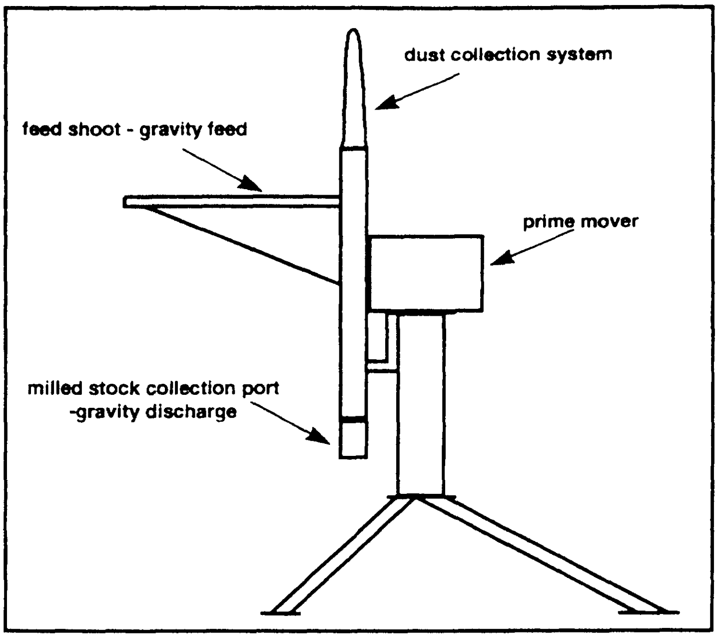

Figure F2. Schematic representation of gravity feed-gravity discharge TD Hammermill

During the trials two different sieve screens were trailed, namely 1.5mm and 1.0mm diameter holed sieves. These were purchased from Saro Engineering, Lusaka. The specification of the sieves is shown in Table F1. This data shows that the steel is of the same gauge thickness and the number of holes per square centimetre of the 1.5 mm diameter hole is less than that of the 1.0mm.

Sieve hole diameter / mm	Sieve thickness / mm	Hole density / no.per.sqr.cm
1.0	1.2	55
1.5	1.2	32

Table F1. Specification of sieve materials used.

The trails were carried out in order to determine the direct costs of milling; i.e. labour and fuel costs. Therefore the milling trails were carried for known periods of time and for known amounts of petrol. The mill was hand fed with as received limestone such that the engine was running at maximum efficiency and not overloaded. This was regulated by the sound of the running engine.

Sieve analysis of the as received as well as ground product was carried out by Civil Engineering, the University of Zambia, using standard sieves according to the British Standard.

4. RESULTS

4.1. Milling performance

The milling efficiencies achieved during the milling trails are shown in Table F2. These results show that using the 1.0 mm sieve it took 0.295hours and 0.325 litres of fuel to produce 42kg of milled output and using the 1.5mm it took 0.246hrs and 0.275litres of fuel to produce 43kg of milled output.

Sieve size / mm	Weight lime milled / kg	Weight lost / %	Time taken / hr	Fuel used / l
1.0	42	16	0.295	0.325
1.5	43	23	0.246	0.275

Table F2. Output results from milling trails.

During the trails, ground limestone dust was observed to come from around the discharge point due to the bad seal between the bag and the unit. The material loss was 16% and 25% by weight, of the original feed material for the 1.0mm and 1.5mm sieves respectively.

Following the milling trials the equipment was inspected for damage and it was observed that the 1.0mm holed sieve had been perforated during the trials. The 1.5mm sieve sustained no physical damage.

4.2. Particle size analysis

The particle sizes of the as received material, ground through the 1.5mm sieve and ground through the 1.0mm sieve are shown in Tables and Figures F3 and F4.

These results show that the raw material was reduced in size from 29.5 % below 2mm to 95-100 % below 2mm. With the 1.5mm sieve 74.4% of the product was smaller that 0.4mm and with the 1.0mm sieve 79.5% was smaller than 0.4mm.

Particle size / mm	10	5	2	1	Pan
% finer	82.2	55.8	29.5	20.6	0

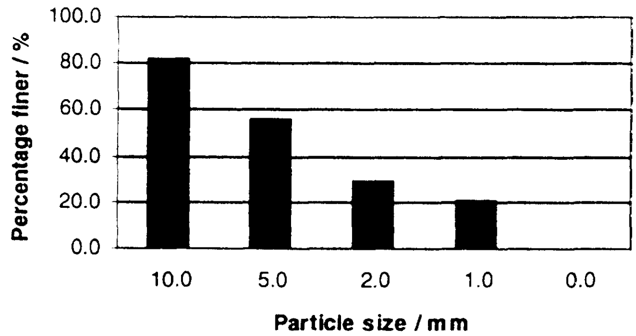

Table and Figure F3. Dry particle size analysis of raw material

Particle size / mm	2	1.5	1	0.4	0.1	Pan
1.5mm sieve - % finer	96.1	94	90.8	74.4	63.9	0.1
1.0mm sieve - % finer	97.5	95.7	92.8	79.5	79.3	19.2

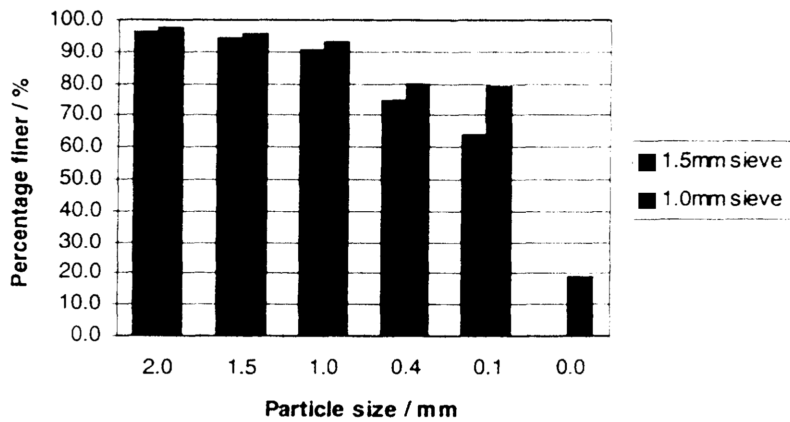

Table and Figure F4. Dry particle size analysis of milled materials

5. DISCUSSION AND CONCLUSION

The milling performance achieved, as analysed in Table F5, shows that the 1.5mm sieve has higher productivity than the 1.0mm sieve by approximately 20%. This is due to the increased work that is required to grind the lime to a finer particle size.

Sieve size / mm	Weight lime milled	Output per hour / kg	Output per litre / kg
1.0	42	142	129
1.5	43	174	156

Table F5. The milling efficiencies per hour and per litre for different sieve sizes.

The particle size of the milled output against the target values is shown in Table F6. This shows that both sieves achieve the required output in that the product was all finer than 2mm and more than 40% was finer than 0.4mm. Further analysis would be required to investigate the dissolution rates of the two limes when used in the field.

% finer	Target	1.5mm sieve	1.0 mm 2.0 sieve
less than 2mm	100	96.1	97.5
less than 0.4mm	40	74.4	79.5

Table F6. The particle size of the milled output.

Analysis of the costs of production per kg of lime milled is shown in Table F7 and Figure F5. These calculations are made assuming a labour cost of 187.5 ZKw (Zambian Kwacha) per hour (i.e. 30,000 ZKw for a 48 hour week, 48 week year) and a fuel cost of 1022ZKw per litre.

Sieve size / mm	Total cost-labour ZKw / kg	Total cost- fuel ZKw / kg	Total direct cost ZKw / kg
1.0	1.32	7.91	9.23
1.5	1.07	6.69	7.76
Average	1.20	7.30	8.50

Table F7. Cost analysis of milling trails

The cost of milling one kg of lime is 7.76 ZKw per kg for the 1.5mm sieve and 9.23 ZKw per kg for the 1.0mm sieve. This cost difference can be suggested to be due to differences in productivity of the two set ups.

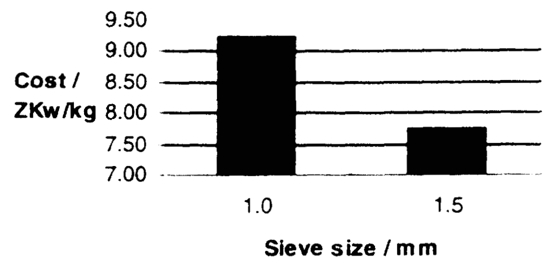

Figure F5. The cost of milling agricultural lime per kg as a function of sieve size

Within this cost analysis the cost of the raw materials or the capital cost of the mill has not be taken into consideration. If the milling were done as a service a cash flow approximation can be made. This has been attempted, as is shown in Appendix 3, for two scenarios; firstly when the mill is running at full capacity and a service charge of 50 ZKw is made and secondly when the mill is running at 50% capacity when a service charge of 25 ZKw is made. In these cases average productivity figures are taken and not specific results for each of the sieves.

These calculations show that the service milling of aglime is a viable business and that incomes in the range 1,000,000 ZKw to 100,000 ZKw per month can be made depending on market conditions[1].

From these investigations it can be concluded that using the TD Hammermill, aglime can be milled for use as an agricultural input and this can be achieved at a price of approximately 8.5 ZKw per kg milled.

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[1] The assumptions made during these calculations are also shown in Appendix 3 and it should be noted that these figures are not the true amounts that could be made using the TD Hammermill.

Appendix F1 - Some cash flow analysis for service milling of limestone

Assumptions made:

1. The cost of the mill is 3,500,000ZKw. Payment is made by a 10% down payment in the first month followed by 36 monthly repayments at a non compound interest rate of 32% ; i.e. monthly repayments of 115,500; total repaid 4,158,000ZKw
2. Fuel costs are 1022 ZKw per litre.
3. Labour costs are 30,000 ZKw per month, 40 hour week, 48 week year.
4. Transport allowances of 2,000 ZKw a working day.
5. Consumable and miscellaneous costs of 15,000ZKw per month.
6. February 1998 exchange rate 1US$ = 1532 Zambian Kwacha

Cash flow: 1,256 Kg per day at 50ZKw service charge per kg

		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Number kg pd	1,256												
Number working days pm		28	24	24	24	30	24	24	30	24	30	24	24
Price per kg/ZKw	50												
Month		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Cash Inflow													
Sales		1,758,400	1,507,200	1,507,200	1,507,200	1,884,000	1,507,200	1,507,200	1,884,000	1,507,200	1,884,000	1,507,200	1,507,200
Cash out													
Loan repayment			115,500	115,500	115,500	115,500	115,500	115,500	115,500	115,500	115,500	115,500	115,500
On fixed assets													
hammermill		350,000											
Operating expences													
fuel		254,944	218,523	218,523	218,523	273,154	218,523	218,523	273,154	218,523	273,154	218,523	218,523
consumables		10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
transport		56,000	48,000	48,000	48,000	60,000	48,000	48,000	60,000	48,000	60,000	48,000	48,000
wages		30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Other													
insurance		20,000											
misc		5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Total cash flow out		725,944	427,023	427,023	427,023	493,654	427,023	427,023	493,654	427,023	493,654	427,023	427,023
Total net cash flow		1,032,456	1,080,177	1,080,177	1,080,177	1,390,346	1,080,177	1,080,177	1,390,346	1,080,177	1,390,346	1,080,177	1,080,177
Running total		1,032,456	2,112,633	3,192,810	4,272,987	5,663,333	6,743,510	7,823,687	9,214,033	10,294,210	11,684,557	12,764,733	13,844,910

Cash flow: **628 Kg per day at 25ZKw service charge per kg**

Number kg pd	**628**												
Number working days pm		28	24	24	24	30	24	24	30	24	30	24	
Price per kg/ZKw	**25**												
Month		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Cash Inflow													
Sales		439,600	376,800	376,800	376,800	471,000	376,800	376,800	471,000	376,800	471,000	376,800	376,800
Cash out													
Loan repayment													
On fixed assets			115,500	115,500	115,500	115,500	115,500	115,500	115,500	115,500	115,500	115,500	115,5(
hammermill		350,000											
Operating expences													
fuel		127,472	109,262	109,262	109,262	136,577	109,262	109,262	136,577	109,262	136,577	109,262	109,26
consumables		10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,0(
transport		56,000	48,000	48,000	48,000	60,000	48,000	48,000	60,000	48,000	60,000	48,000	48,0(
wages		30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,0(
Other													
insurance		20,000											
misc		5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,0(
Total cash flow out		598,472	317,762	317,762	317,762	357,077	317,762	317,762	357,077	317,762	357,077	317,762	317,76
Total net cash flow		-158,872	59,038	59,038	59,038	113,923	59,038	59,038	113,923	59,038	113,923	59,038	59,03
Running total		-158,872	-99,833	-40,795	18,244	132,167	191,205	250,244	364,167	423,205	537,128	596,167	655,20

F10

Plate F1. TD hammer mill, TDAU, UNZA

Plate F2. Ground carbonate, product of TD hammer mill

SECTION G:
LOCAL DEVELOPMENT OF AFFORDABLE LIME IN SOUTHERN AFRICA WORKSHOP

A workshop "Local development of affordable lime in Southern Africa" was held in the Mupani 2 room of the Pamodzi Hotel, Lusaka on Friday 27th February 1998. The workshop was held to disseminate the findings and results of the BGS/DFID TDR project "Local development of affordable lime in Southern Africa" (R6492). Fifty delegates attended the workshop from a wide range of backgrounds (see delegate listing). The workshop schedule, opening address and abstracts from each of the presentations are reproduced here.

8.30 Registration
9.00 Brief introduction & welcoming address

Welcoming address by Mr Davison Mulela, Director of the Geological Survey Department, Ministry of Mines and Minerals Development

Mr Chairman, BGS officials, organising committee, foreign and local resources personal, Heads of Departments, distinguished guests, Ladies and Gentlemen.

It is my pleasure to welcome all delegates to Zambia in general and more particularly to Lusaka to attend the workshop on the Local Development of Affordable Lime in Southern Africa, sponsored by the UK Department for International Development (DFID), Technology Development and Research (TDR) through the British Geological Survey (BGS).

Ladies and Gentlemen, liming is among the oldest practices of agriculture. It has been known to farmers for centuries to be an essential of crop husbandry and yet, even in this scientific and technical era, farmers are sometimes apt to overlook the basic truth. The problem of poor crop yields associated with acid soils of northern and north-western parts of the country are well documented. The Zambian government has been aware of this issue for a number of years and has acted to improve matters in terms of increasing the supply of agricultural lime within Zambia. For example, the former Minex department of ZIMCO investigated the agricultural lime potential of limestone and dolomite deposits throughout Zambia in the 1980s.

Further more, in 1990 the SADC Mining Co-ordination Unit commissioned the AUSTROPLAN project to look at issues and demand for lime in Central and Southern Africa. It should also not be forgotten that the Ministry of Mines and Minerals carried out, through UNDP/UNIDO, feasibility studies to increase agricultural lime production in Northern and North-western provinces.

The market for agricultural lime in Zambia remains somewhat stagnant. This lack of demand has been linked to poor availability of agricultural lime in many areas. In the past, the approach has been to try to establish high-capacity crushing plants placed strategically at certain localities within Zambia. Unfortunately, such plants require a substantial amount of capital investment and if they are operated below capacity then they would high production costs. Since such facilities are highly centralised, transport costs for agricultural lime can also be prohibitive.

More recently, a project involving the Geological Survey Department of Zambia, the NGO Intermediate Technology Zimbabwe and the British Geological Survey has adopted a "grass roots" approach to the supply of agricultural lime. Local, small-scale production of agricultural lime close or adjacent to the areas of need, using appropriate technology, is being investigated. The aim is to create a "virtuous circle" whereby the use of agricultural lime is stimulated by increasing its availability and reducing transport costs.

9.30 Overview: Lime

Mr Clive J Mitchell, Workshop Co-ordinator, British Geological Survey

Strictly lime is calcium oxide (CaO), but broadly it is a term that applies to a wide range of calcium-rich products, including crushed/ground limestone and burnt/hydrated lime. Lime is produced from limestone and dolomite by crushing and grinding, or crushing and calcining. Zambia has a surfeit of burnt lime, most of which is used in copper refining. Production of ground limestone for use as agricultural lie is limited to the provincial centres of Ndola, Kabwe and Lusaka. Many studies have been carried out over the past 20 years and have identified the problems associated with the use of agricultural lime to be essentially its high cost and poor availability. Those users with the greatest need for agricultural lime are in the Northern provinces of Zambia. As part of the UK governments commitment to provide technical assistance to developing countries a project was initiated to encourage the development of locally available, low cost agricultural lime. This project involved the following:

i) Lime evaluation programme, which set out to identify carbonate resources suitable for use as lime close to the point of need;
ii) Small-scale lime production research, which aimed to identify a low cost method for the small-scale production of lime, using appropriate technology;
iii) Dissemination, which involved a workshop on the findings of the project

In conclusion, as suitable carbonate resources exist close to the point of need and production methods and technologies also exist, it was considered that production of locally available, low-cost agricultural lime is achievable.

10.00 Agricultural lime potential of Zambia: A review

Mr Simon Inglethorpe, British Geological Survey

Existing production of agricultural lime is focused in the regional centres at companies such as Crushed Stone Sales Ltd in Lusaka, Lilivale Farm in Kabwe and Ndola Lime Ltd in the Copperbelt. The agricultural lime potential of selected carbonate resources throughout Zambia has been investigated by the former MINEX Department, including deposits in North-western, Copperbelt, Eastern, Luapula and Southern provinces. Previous lime production and feasibility studies, such as the comprehensive study by NORAGRIC, have reviewed the factors controlling production and consumption of agricultural lime in Zambia. The present day scenario sees an effective lack of demand for aglime, due mainly to poor availability and costs of transportation. These studies recommend the establishment of expensive relatively high-capacity plants at strategic sites throughout Zambia. However, recent projects arising from such studies, such as those at Chivuna and Mkushi, have not resulted in any significant increase in output. This is due mainly to a lack of capital and perceived demand for agricultural lime. The way forward may be to adopt a "grass roots" approach, whereby local small-scale production units could be established to serve discrete farming communities. Gradually increasing the availability of affordable lime may ultimately encourage the development of larger scale production.

10.30 Tea & coffee break

11.00 Agricultural lime: Testing of limestone & dolomite

Mr Simon Inglethorpe, British Geological Survey

Agricultural lime has long been accepted as necessary to condition soils, especially to accommodate the intensive farming practices of the developed world. However despite this, agricultural lime is still under-utilised. Many definitions for aglime exist, but essentially it is ground limestone and dolomite. The key properties of required of aglime are as follows:

i) Plant nutrient content. Expressed as the calcium & magnesium oxide content.
ii) Particle-size. Ideally, aglime should contain 80% finer than 2.36 mm, although the critical size range is 0.85 to 0.15 mm.
iii) Neutralisation ability. Amelioration of soil acidity is the prime function of aglime. Neutralisation ability is usually expressed as the Calcium Carbonate Equivalent (CCE).
iv) Agronomic effectiveness. Expressed as the reactivity, or the rate at which aglime neutralises soil acidity.
v) Ease of pulverisation, or the grindability. A measure of the hardness of the limestone or dolomite, which is a useful production parameter.

Laboratory trials were carried out to determine these key properties and the results were presented.

11.30 Ameliorating soil acidity using lime and combinations of lime and organic matter or gypsum

Dr Olesegun Yerokun, Department of Soil Sciences, School of Agricultural Sciences, University of Zambia (UNZA)

Soil acidity limits crop production in several parts of the world. It is prevalent in humid regions with high rainfall that has resulted in leaching of base cations as well as accelerated weathering. In Zambia the region covering Copperbelt, Luapula, Northern and North-Western provinces is dominated by low activity clay Ultisols and Oxisols. As a result of the wide occurrence of acid soils in the country, it became necessary for the Research Branch of the Ministry of Agriculture Food and Fisheries to conduct lime trials. This research was concentrated in Northern Province because of the soil acidity as well as the strategic location of the Soil Productivity Research Programme (SPRP) there. There have been two major contributions to agricultural lime research by the School of Agricultural Sciences. One study by the team of Dr OI Lungu examined lime and manure combinations as amendments on acid soils. The other study by the team of Prof. VRN Chinene used lime and gypsum combinations for subsoil acidity amelioration. In the first study it was found that combinations of lime and farmyard manure significantly increased maize grain yield, although the use of lime alone did not produce an increase. The second study found that combinations of lime and gypsum also significantly increased maize grain yields, with the gypsum enhancing the effectiveness of the lime. A summary of the data from the UNZA Soil Analytical Laboratory (UNZASAL) indicates that as much as 45% of the samples tested are acid soils. The constraints on lime use and the 'way forward' are highlighted. Constraints include prohibitive transport costs, poor packaging, lack of lime spreading equipment and lack of investors in lime production. Recommendations for the 'way forward' include government involvement in procuring equipment & devising tax breaks for potential investors, subsidies on transportation, an acid soils liming programme and education as to the benefits of using lime.

12.00 Evaluation of Nampundwe mine tailings as a source of agricultural lime under field conditions

Moses Mwale, Luckson Phiri and MI Damaseke, Mount Makulu Central Research Station

There are considerable amounts of dolomitic Nampundwe mine tailings as a by product. At the request of ZCCM, laboratory tests and a pot experiment were done on the tailings to evaluate their potential as a liming material. Upon the successful completion of these experiments, a field study was instituted to further evaluate the effectiveness of the tailings as a source of lime to major crops. The field experiments were conducted at Mkushi (soil pH 4.8), Kabwe (soil pH 5.0) and Kasama (soil pH 4.3). Maize and soyabeans were planted in November, 1995. Nampundwe mine tailings and calcitic agricultural lime from Crushed Stone Sales Limited in Lusaka, used as reference material, were applied at rates of 2000 Kg ha^{-1} at Kasama, 200 Kg ha^{-1} at Mkushi and 800

Kg ha^{-1} at Kabwe. Treatments were replicated four times in a randomised complete block design. The experiment was repeated in 1996/97 season and sites at Kasama and Mkushi were maintained to study the residual effects of the lime. Further, new sites were used, where lime was applied at 0, 1000, 2000 and 3000 Kg ha-1 for soyabean at Kasama and Mkushi but not at Kabwe in 1995/1996 season. Similar results were obtained at Kasama and Kabwe in the 1996/97 season. However the residual tailings raised the soil pH to the level of agricultural lime at Kasama in the following year. Agricultural lime reduced the soil exchangeable Al at Kasama and Kabwe except at Mkushi. Both the tailings and the agricultural lime increased the levels of soil Ca at Kabwe and Kasama but not at Mkushi. Levels of Mg, Zn, P and cation exchange capacity remained unchanged in all the three locations in the 1995/96 season but the tailings increased the levels of Mg in the 1996/97 season. At Kabwe the tailings did contribute some Fe to the soil. He dry matter yield of the sorghum at Kasama showed that Nampundwe tailings and agricultural lime were better than the unlimed plots where sorghum completely failed to grow. Liming did not significantly increase the yield of maize and soyabeans in all the three locations in both seasons. Generally the results showed that the Nampundwe tailings may be used as a liming material. It has the potential to increase the soil pH and release certain plant beneficial elements like Ca, Mg, Zn and Fe to the soil. The levels of heavy metals were found to be negligible in soils treated with the tailings.

12.30 Lunch

14.00 Carbonate resources of Zambia

Mr S Mabuku, Geological Survey Department, Ministry of Mines & Minerals Development

Zambia is underlain by a crystalline basement of Lower Precambrian age, which can be sub-divided into the older Lufubu (metamorphic basement terrain) and the younger Muva Supergroup (metasedimentary and metavolcanic sequences). The carbonates of the Lufubu are poorly documented, whereas the Muva Supergroup consists of dolomitic and calcitic marbles occuring from Lusaka through to Northern province. The basement is unconformably overlain by the Upper Precambian Katanga Supergroup (clastic and carbonate sequences). The Katanga contains most of Zambia's carbonate resources, typically as dolomitic and calcitic marbles occurring from Southern Province through to North-Western Province. Most of the currently worked carbonates occur in the Katanga, such as that exploited by Chilanga Cement Ltd and Ndola Lime Ltd. The Katanga is overlain by Lower Palaeozoic rocks (essentially devoid of carbonates), the Karoo Supergroup (Carboniferous to Lower Cretaceous) which contains few carbonates and the Kalahari Group (Late Tertiary to Recent) which contains calcrete. The carbonatite at Nkombwa hill is the most significant of the remaining unmentioned carbonates and contains a significant amount of dolomitic carbonatite.

14.30 Agri-lime production using appropriate technology

Mr Peter Tawodzera & Mr Alfred Kufa, Intermediate Technology Zimbabwe

A review of the methods used by small-scale lime producers was carried out as part of research aimed at identifying low cost methods of producing lime. Intermediate Technology Zimbabwe carried out the review by visiting operations throughout Zimbabwe and assessing their methods of extraction and processing. The various operations involved in the production of lime include stripping of overburden, extraction/quarrying, stone dressing, crushing, grinding/milling, screening, bagging/packaging (and calcination/lime burning for burnt lime). The costs of manual and mechanical production methods were determined.

15.00 Agricultural lime production in Zambia and research possibilities

Dr Stephen Simukanga, School of Mines, University of Zambia

Carbonate rocks have long been used in agriculture to improve crop growth and soil fertility. The major use of agricultural lime is to neutralise soil acidity. Carbonates occur in all provinces of Zambia except Western province. The production of agricultrual lime is mainly from three main sources; Ndola Lime Company, Crushed Stone Sales and MINDECO Small Mines. The production of ground agricultural lime simply involves quarrying, crushing and grinding to suitable sizes. Agricultural lime has an optimum particle-size between 3 and 0.1 mm and a MgO content of at least 3%. Average annual production is about 37,000 tonnes, whereas the average annual requirements for agricultural lime are estimated to be about 131,400 tonnes. Local sources of agricultural lime are required. Some of the issues affecting the success of small-scale mineral operations include: little understanding of the market requirements, ignorance of other applications for limestone, lack of know-how &/or capital for lime production and lack of government incentives. In order to help the small-scale operators the following research would be appropriate: compilation of technical information of limestones & their suitability for use as agricultural lime, the effectiveness of agricultural lime for particular soil types; appropriate and simple production techniques for lime production, and education as to the alternative uses of limestone.

15.30 Soft drinks

16.00 Legal, environmental and performance aspects of the limestone sub-sector in Zambia

Cris Muyunda, Head of Projects, Ministry of Mines and Minerals

Limestone, classed legally as a building mineral in Zambia can be searched for or developed under small scale or large scale mining operations. The Mines and Minerals Act, 1995 and its subsidiary legislation provide various provisions regulating the limestone as well as other mineral sub sectors. In particular, Statutory Instrument number 29 of 1997, Mines and Minerals (Environmental) Regulations, provide guidelines on environmental requirements developers need to be aware of before undertaking any prospecting, exploration or mining operations.

With regard to performance in the limestone sub sector, Zambia has the most developed industry in SADC outside South Africa. The portfolio of production in the sub sector includes limestone aggregates, quicklime, hydrated lime and agricultural lime. Annual total production of these materials hovering around the 1,000,000 tonne mark during the 1980s fell during the 1990s to some 700,000 tonnes per annum. This drop was basically due to the reduction in demand from the base metals sector. However, demand in other user sectors such as water treatment, effluent treatment, agricultural and construction uses is likely to see a renaissance in output. This, together with the expected recovery in the base metals sector, as result of privatisation, guarantees a prosperous entry into the 21st century for the sub sector in Zambia.

16.30 The milling of agricultural lime with the TD hammer mill

Dr Simon Bradwell, Technology Development & Advisory Unit, University of Zambia

Milling trials were carried out using the TD hammer mill to produce agricultural lime from mined product. The TD hammer mill consists of 12 steel hammers, driven by a petrol engine, and an integral product screen. The aim of the trials was to determine the milling capacity, cost and particle-size of ground product. Two different sieve screens were used, with 1.5mm and 1.0mm diameter apertures respectively. The trial using the coarser screen produced a higher milling capacity (174 kg/hr), lower production cost (US$4.76 per tonne) and slightly coarser particle-size (64% finer than 100 microns) than the trial using the finer screen. Cash flow approximations for operation of the hammer mill indicate that production of agricultural lime is economically viable.

17.00 Summary: Brainstorming the way forward

Mr Clive J Mitchell, Workshop Co-ordinator, British Geological Survey

A summary of the brainstorming session held, at the end of the workshop, to determine the 'way forward' to encourage the production and use of agricultural lime in Zambia:

i) Agronomic research must demonstrate the economic benefit of liming.
ii) The introduction of acid soil tolerant crops could partly solve the problems of low crop yields in these areas.
iii) The benefits of the use of agricultural lime need to be directly demonstrated to farmers.
iv) The use of rail and associated distribution centres could help offset the high cost of transporting agricultural lime to the point of need.
v) Identifying the most appropriate form of agricultural lime for specific soil types may allow more efficient use of lime.
vi) Targeted subsidies and tax-breaks to encourage the use and production of agricultural lime.
vii) A better understanding of the technical qualities of agricultural lime could possibly allow its use to be more effective.
viii) Development of small-scale production of agricultural limes using appropriate technology.
ix) The availability of lime spreaders and technical back up for consumers of agricultural lime.

18.00 Close

APPENDIX G1:
WORKSHOP DELEGATE LISTING

Local development of affordable lime in Southern Africa Workshop
Mupani 2, Pamodzi Hotel, Lusaka, Zambia 27th February 1998

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APPENDIX G1:
WORKSHOP DELEGATE LISTING continued

Local development of affordable lime in Southern Africa Workshop
Mupani 2, Pamodzi Hotel, Lusaka, Zambia 27th February 1998

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SECTION H:
RECOMMENDATIONS FOR THE EVALUATION AND SMALL-SCALE PRODUCTION OF LIME

The recommended procedures for the evaluation and small-scale production of lime are summarised below. Figure H1 gives a flowchart for the suggested small-scale production of lime.

Recommended survey of lime market & carbonate resources

1. **Market survey** to determine the nature of the lime market, the quantities & qualities required, plus the constraints on production and consumption (as carried out for agricultural lime in Zambia and detailed in Section A).

2. **Review of carbonate resources** to identify the locality and nature of the limestone and dolomite resources (as carried out for Zambia and detailed in Section B).

Recommended laboratory evaluation procedures

1. **Identification of laboratory procedures** for the evaluation of limestone and dolomite for use as lime (as carried out for agricultural lime in Zambia and detailed in Section C).

2. **Lime evaluation programme**, involving sampling of limestone & dolomite, evaluation in a dedicated testing laboratory and identification of those suitable for use as lime (as carried out for agricultural lime in Zambia and detailed in Section D).

Recommended small-scale lime production procedures

1. **Review of small-scale production methods and practices** to identify the most appropriate procedures for the type of limestone & dolomite resources available (as carried out, for lime production in Zambia, by reviewing the small-scale production of lime in Zimbabwe and detailed in Section E).

2. **Small-scale production trials** to determine the suitability of production methods identified in the review (as carried out for agricultural lime in Zambia using a Zambian-built hammer mill and detailed in Section H).

Recommended procedure for the small-scale production of lime

Small-scale production of lime should involve, where possible, manual procedures. Avoiding mechanical production methods reduces the initial capital costs, simplifies the production process and maximises the employment potential. The recommended procedure for the production of lime is summarised as a flowchart in Figure H1. The production process should involve the manual removal of vegetation and overburden, contractors to carry out the necessary drilling and blasting (once or twice a year), manual stone dressing & crushing, mechanical grinding using a hammer mill and bagging. In addition to producing ground limestone and dolomite for use as agricultural lime, this production procedure could also satisfy the demand for aggregate, feed material for the production of burnt lime and, potentially, mineral filler for various applications (e.g. paint).

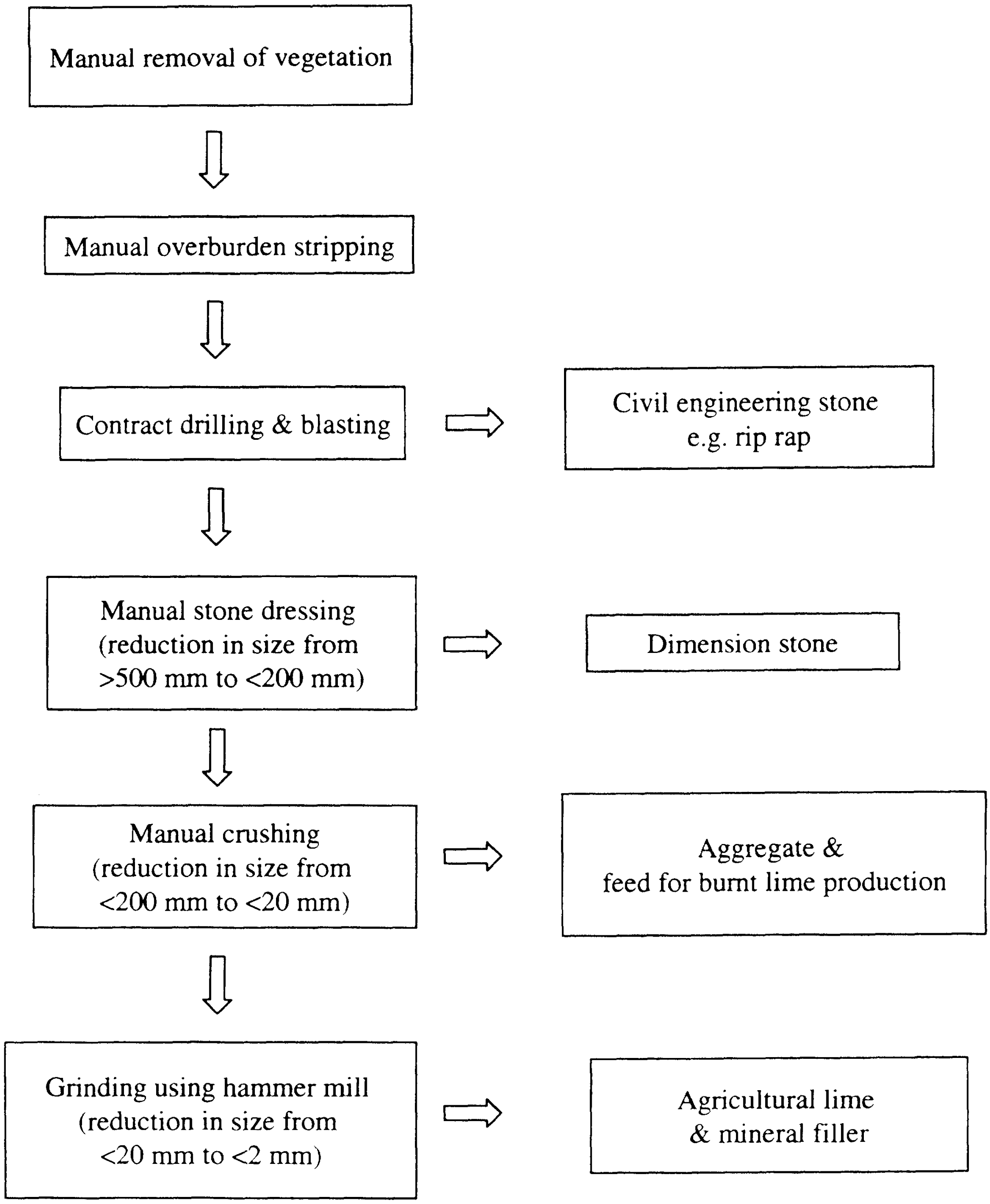

Figure H1. Recommended process route for small-scale production of lime (and other products)

SECTION I:
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