OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

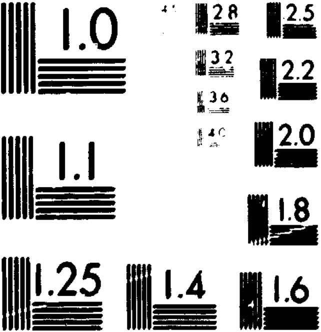
Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

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



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

11457

25

UNIDO-Czechoslovakia Joint Programme
for International Co-operation in the Field of Ceramics,
Building Materials and Non-metallic Minerals Based Industries
Pilsen, Czechoslovakia

Distr.
LIMITED

JP/31/80
April 1980

ORIGINAL: English

In-plant Training Workshop
on the Exploitation and Beneficiation
of Non-metallic Minerals

Pilsen, Czechoslovakia

8 - 26 April 1980

THE EVALUATION AND SPECIFICATION OF ROCK DEPOSITS FOR BUILDING MATERIAL PRODUCTION: LIMESTONES AND NATURAL POZZUOLANAS

By: N. R. Hill [+]

00[illegible]

[+] Consultant on Industrial Minerals and Construction Materials, Portsmouth, United Kingdom

CONTENTS

Page

1. INTRODUCTION 1

2. RAW MATERIAL INVENTORY SURVEYS 3

3. PROCEDURE FOR PRELIMINARY EVALUATION 5

3.1. Information about the Project 5
3.2. Examination of Available Data 5
3.3. Reconnaissance 6
3.4. Field Work 7
3.5. Laboratory Work 9
3.6. Raw Material Cost 10

4. COMPLETE ASSESSMENT 11

4.1. Reserves 12
4.1.1. Definitions 13
4.1.2. Calculation 13

4.2. Performance 14
4.3. Cost Data 15

5. LIMESTONES 16

5.1. Portland Cement Manufacture 17
5.1.1. Chemical Specification 18
5.1.2. Physical Specification 22
5.1.3. "Ideal" Limestones 23
5.1.4. Reserves 24

5.2. Lime Production 26
5.2.1. Chemical Specification 26
5.2.2. Physical Specification 28
5.2.3. Reserves 29

5.3. Aggregate for Concrete 31

ii 6. NATURAL ....

6. NATURAL POZZOLANAS (TRASS, ETC.) 35

6.1. Evaluation in the Field 35
    6.1.1. Volcanic 35
    6.1.2. Amorphous 35
    6.1.3. Colour 35
    6.1.4. Freshness 36
    6.1.5. Uniformity 36
    6.1.6. Location 37
    6.1.7. Accessibility 38

6.2. Laboratory Evaluation 38
    6.2.1. German Procedure 39
    6.2.2. American Procedure 40
    6.2.3. Indian Procedure 40
    6.2.4. Indonesian Procedure 41

6.3. Pozzolana in Concrete 41

Acknowledgement 42

SOME REFERENCES 43

----

1. INTRODUCTION

This Guide to the Evaluation and Specification of Rock Deposits for Building Material Production is the sequel to the author's Guide to the Geological Investigation of Rock Deposits for Building Material Production, which was issued as Technical Report No.15 of Project INS/74/034, Bandung, in February 1977.

Although this Guide is written specifically with the commonly available Indonesian raw materials in mind, it should be applicable in other areas where similar materials occur. From the author's experience in South American countries, as well as Indonesia, there are too few, if any, geologists and chemists, etc. who have the knowledge required for assessing a non-metallic rock or mineral deposit as a potential source of raw material. The reasons for this are well known and this Guide is an attempt at dealing with one of the factors, namely the lack of available literature on the subject. (The other factors will resolve themselves if governments of industrializing countries would ensure that the appropriate emphasis is put on the industrial rock and mineral sector relative to that for the petroleum and metalliferous sectors.)

There are, of course, books on the products, such as cement, lime, heavy clay products, etc., which have chapters on the raw materials. There are also some useful papers such as Vladimir Lach's Testing and Evaluation of Brick Clays (UNIDO Paper : ID/WG.16/2), which consider individual materials for a specific use. What until now appears to be lacking is a reference book which is directed at the geologist working in an industrial research institute for the building material and construction industries of a developing country.

Much of the work will be participation in raw material inventory surveys, usually with the geological survey, and more detailed assessment of particular deposits on which to

- 2 - base a project .....

base a project for production of a specific building material. For this a proper procedure of evaluation has to be conducted which is based on knowledge of the various processes for building material production, the specification for the raw materials and the minimum reserves needed for a particular production capacity. This is described briefly in the chapter on "Procedure for Preliminary Evaluation".

The approach used in the subsequent chapters is to consider some of the more common non-metallic rocks or minerals (limestones, natural pozzolanas, clays, shales and soils, river gravels, industrial sands, etc.) and, for each of its potential uses, discuss the quality specification and the reserves requirement. The third important evaluation factor, cost of the specified raw material delivered to the production unit, is included within section 3.6. and, in more detail, in Section 4.3.

There are numerous other raw materials, not necessarily all available in Indonesia at present, which could be included here but will have to await a revised version of this Guide. These are not only other naturally occurring inorganic materials but also industrial waste or by-product materials such as phospho-gypsum, slags, fly ash, etc. as well as some of the agricultural wastes such as rice husks, etc. The sources of all these potential raw materials for use in building material production can be evaluated most appropriately by considering them "geologically" and applying the type of assessment procedures described in this Guide.

Before making the decision to use a particular deposit as one of the raw material sources for a projected new building materials factory, there are three main factors that have to be known about it. These are :

The quantity of the material and its performance data, preferably following a full-scale trial.

- 3 - The proven ....

The proven reserves available.

The cost of the material, delivered to the factory and ready to enter the process.

There are other considerations, of course, such as the granting of planning permission to work the deposit and any capital costs such as for constructing an access road, bridges, etc. for trucks and equipment to reach the deposit.

The raw materials for manufacture of building material are commonly of low bulk value. This means that transportation charges may become a large and unacceptable proportion of the delivered cost for the raw material unless the deposits are conveniently located in relation to the factory, which itself must be correctly sited with respect to the intended market. (The various items to consider in choosing a site for the factory are dealt with in the author's Technical Paper No.13 "Factors in the Selection of a Site for a Factory for Building Material Production", Project INS/74/034, Bandung, Dec. 1977),

2. RAW MATERIAL INVENTORY SURVEYS.

One of the earliest tasks of a newly established geological section attached to an industrial research Institute (IRI) is to compile an inventory of potential raw materials sources throughout the country, based on region (or province) and rock type.

Normally, the basic data required will have been compiled by the national geological survey office in the course of its field and laboratory work for compiling the complete geological map of the country, eventually on a scale of 1 : 50,000. Regular liaison with the geological survey office, especially its non-metallics section, and collaboration in surveys of potential raw materials such

- 4 - as limestones, ...

as limestones, brick clays, etc., may provide sufficient initial geological data with which to advise provincial planning and industrial development offices on the possibilities for development of the local building materials industry.

If inspection and initial evaluation of deposits in a province is to be carried out, it should be done with full knowledge of relevant previous survey work in the area and in company with one of the geological survey staff who has been there.

During inventory surveys there is not time to do more than make a brief inspection of the deposits, with an approximate estimation of the minimum 'visible' and possible maximum volume of available material and collecting one bag of material for each principle lithological type seen, 5 to 10 Kg, made up of small samples from several places to make the overall samples as representative as possible.

The field data, and a note of any laboratory test results, should be recorded carefully onto a Raw Material Location Report (RMLR) and stored in a simple reference system under "Rock Type" and "Province". This system is explained in the author's Technical Report No. 15, mentioned earlier. Some of the data may be put in reports written at the request of the management, etc. but these cannot effectively substitute for the individual deposit or location report sheets (RMLR'^{s}). After a few years, the number of reports issued will be too many for rapid and effective retrieval of the particular data that is asked for. Eventually, only a computerized data storage system will be able to handle the information and the use of a data card (RMLR) system from the beginning will facilitate the eventual transfer of the information to the computer.

- 5 - 3. PROCEDURE FOR ..

3. PROCEDURE FOR PRELIMINARY EVALUATION.

The typical situation under consideration here is dealing with the request from an industrialist or a government industrial planning department, for assistance in selecting suitable sites for establishing new factories to meet the future market demand. In the case of new cement or lime plants, it means locating suitable deposits of limestone with the possibility of building the factory close to them. The same applies to projects for brick or tile production, where adequate reserves of clay or shale of the right quality have to be found with the possibility of establishing a factory at the same place.

3.1. Information about the Project.

The first step is to confirm the relevant details of the project by means of a meeting with the manager in charge of the project. Technical Paper No.13 describes this and the following is the check-list of data for the briefing of the field survey personnel :

Approximate location for the factory
Raw material quantities needed and preferred
    characteristics or minimum specification.
Probable production capacity and types of product.
Operating life.
Proposed market.
Process characteristics.
Any effluents.
Water, electricity, manpower, etc.
Land area required for the factory (in hectares).

3.2. Examination of Available Data.

One or two days should be spent inspecting various maps such as the 1 : 100,000 and 1 : 50,000 topographic maps, the available geological maps and any land use maps

- 6 - as well as any .....

as well as any published development plans for the general area. The information obtained will considerably reduce the number of possible locations which have to be inspected in the field. The collaboration of locally based geological survey personnel at this stage can be highly beneficial. Likewise, the possibility of unforeseen developments such as proposed reservoirs, national parks or restricted military zones can be learned by discussion with the development planning personnel in the local government office. The existence of small traditional building material industries in a particular area may suggest the possibility of suitable raw material being found there. Usually, though, the small brick and tile factories are using only the thin surface clay layers. These may be all that exist and any deeper clay material, upon which modern plants have to be based, often will be of inadequate plasticity.

3.3. <u>Reconnaissance</u>.

After inspection of the available maps and reports and elimination of obviously unsuitable areas, a tour of the most promising of the remaining localities can be planned. Here again, the participation of the area geologist from the office of the geological survey as a guide for the field party will save time. The presence of the project manager, during this period of two or three days of reconnaissance, will help ensure that localities selected for preliminary evaluation are practical. It will also assist the project manager in his de-briefing of the field party if he knows the general nature of the locations under consideration.

Raw material which to the eye may appear suitable can perform badly during the laboratory evaluation test programme. Hence, the reconnaissance should find, if possible, between 4 and 6 localities for preliminary

- 7 - evaluation based ....

evaluation based on the likelihood of their satisfying the factors listed in section 3.1.

It has been said that "time spent on reconnaissance is seldom wasted". This is particularly true in the case of field work for the evaluation of raw material sources and the selection of sites for factories.

3.4. Field Work.

The purpose of the field work done at this stage of the evaluation process is only :

1) to determine that there is a very good probability that sufficient material would be available.
2) to determine the principle lithologies present and the degree of uniformity or continuity of the deposit.
3) to obtain a representative sample of the two or three principle rock types upon which the laboratory analytical and testing work can be performed.

For hard rock deposits such as limestones, there will be exposures such as cliffs, road cuttings or existing small quarries, which can be used for compiling a stratigraphic section, showing thickness and lithological types at several places along the deposit. The representative samples for testing have to be from beneath the weathered surface. If recent fresh exposures are not available then one or more has to be made, by digging a trench or test pit. In harder rocks it means using pneumatically operated tools or small explosive charges in which the co-operation of the local military authorities could be advantageous, as well as necessary in certain countries. The use of a specialist contractor for drilling some boreholes is an unwarranted expense

- 8 - at this stage .....

at this early stage : unless one is available locally and can conveniently drill one, or at the most two, boreholes to pre-selected depths on each of the 4 to 6 initial localities.

Soft rock formations seldom show good exposures, except sometimes on the outside of a river bend or a recent road cutting. Water wells recently dug are of great value but wells that have been dug long ago can give only an indication of the likely thickness of a formation. Samples taken from the wall of these older wells may consist of sandy clays from which the finer material has been elutriated by the water due to the seasonal rise and fall of the water table level,etc. Auger holes which,with extension rods,can be drilled by hand to 8 m or more, can be relatively quick and inexpensive and yield sufficient information about bed thicknesses and lithologies. Difficulties occur if unweathered boulders are encountered. A good compromise procedure is to dig one trial trench, or deep test pit, close to the "centre of gravity" of the particular deposit under investigation and bore between 4 and 6 bore holes by hand auger at selected points towards, but not too close to, the periphery of the deposit. The test pit is used as the sampling point of the various layers and the boreholes, together with the test pit, provide the evidence regarding lithological uniformity and continuity of the individual horizons. Alternatively, a part of the material from each borehole can be mixed together, keeping distinct layers separate, to form overall representative samples upon which to do the laboratory evaluation work.

During sampling, (which is discussed in more detail in a Technical Paper in preparation by Frits Dirks, in the Project INS/74/034 series, of papers) one must have in mind the likely mining or quarrying procedure and

- 9 - whether it will .....

whether it will be feasible to remove the various lithologies separately, which, from the process control viewpoint, would be preferable. This applies particularly to high and low calcium content layers in limestones for cement manufacture and also to the plastic clayey and less plastic silty-sandy layers in clays for production of structural clay products.

Estimation of the surface area of the deposit, at this preliminary stage, can be done by visual estimation and pacing - provided one has checked how many paces are equivalent, approximately, to 100 metres. The bed thickness is determined by averaging the amounts recorded in the boreholes and test pit. Together these give a figure in cubic metres for the estimated "reserves". (The terminology and accepted definitions for the various categories of "reserves" are given in Section 4.1.)

3.5. Laboratory Work.

Whereas the procedure for determination of the quantity of available raw material in a deposit is fairly standard, as explained in the preceding Section, the evaluation data to determine the quality or potential performance of a particular raw material are too varied to summarise in general terms. They are dealt with, together with examples of typical quoted specifications and relevant points about the processes, in Chapter 5, onwards.

Some general points that follow, which are applicable to the quality testing of all potential raw materials, are based on the author's observations on analytical procedures used in some developing countries. Usually too much analysis is done which lacks relation to the potential industrial uses of the material. Thus, for example, many samples of trass (for blockmaking) and

- 10 - shales (for .....

shales (for lightweight aggregate) are being submitted for chemical analysis, X-ray diffraction analysis, etc. In fact, in most cases the appropriate tests would be to determine the pozzolanic activity of the trass by the strength development of trass-lime mixes and carry out bloating tests on the shales over a range of temperatures. At a later date, when funds are available for more basic 'research', in conjunction with work for university theses, etc., the retained permanent reference samples of the trass and shales can be analysed in more detail and the results correlated with the strength and bloating results.

Samples are being submitted to the analytical sections without prior consultation over the quantities required, the preparation of the material, the potential use and, hence, the appropriate tests to make.

The results of the preliminary laboratory evaluation will enable the deposits selected for initial appraisal to be placed in order of performance and show also what mixes or treatment may be required. Provided that the deposit that performs best also satisfies the requirements for the quantity of available material, its delivered cost to the factory (to be considered in the next section 3.6.) and the location for the factory, then that deposit can be used for calculations in the feasibility study. Later, at the start of work on the full project proposal, the deposit will be explored in detail to prove the reserves and select material for use in plant trials ("Final Assessment" is considered briefly in Chapter 4.)

3.6. Raw Material Cost.

At the preliminary evaluation stage it is not necessary to determine in detail the various costs that together make up the total delivered cost of the raw material to a specification fit for the process. Some indication of cost is essential for use in the feasibility study. An acceptable figure can be gained by getting estimates from local contractors who deliver materials in the area of the proposed project development. The factors that will most influence the overall cost are the price for the land, the distance and difficulty of access from the deposit to the factory, thickness of overburden and any special separation or pre-treatment process that would be necessary.

The subject of raw material cost is considered more fully in Section 4.3.

4. COMPLETE ASSESSMENT.

A complete detailed investigation of a deposit of potential raw material is made only after the results of the preliminary evaluation have been found to be satisfactory and the feasibility study indicated good economic and social benefits to be likely.

For multi-million dollar projects, such as cement plants and larger brick factories, the organization of the field work for proving the existence of sufficient reserves of suitable raw material is placed by the project consulting engineers in the hands of a specialist sub-contractor for carrying out the drilling of the boreholes. The analytical work can be contracted either to the appropriate national research institute (IRI) which serves that industry or to some other recognized local laboratory.

In many large projects the engineering consultants, especially if they are also participants in the venture, may insist that foreign based facilities be used for the final assessment work on the raw material. Therefore, for the carrying out of full scale trials in a plant, it may be

- 12 - necessary to .....

necessary to send several tonnes of the material to an industrialized country for processing there. However, wherever possible, testing and trials should be conducted within the developing country itself, provided the facilities exist. There is the risk that the production or treatment process selected may not be the most appropriate to the local conditions if the test facilities of a foreign equipment supplier are used. It is most important that independent advice, from a consultant or organization known to be not linked to a particular supplier, is obtained before a particular process or system is selected. There have been many instances where the production system used has not been appropriate because the consultants or the local official charged with taking the final decision made their recommendation or choice mainly on the basis of the amount of commission they would receive from the supplier of the equipment. It is a situation which is very difficult, or impossible even, to avoid unless there is close and impartial participation by knowledgeable counterparts.

Generally, for smaller projects, such as lime kilns, concrete products factories, medium sized brick or tile plants and also new demonstration plants, the whole project proposal including the detailed raw material assessment, should be within the capability of the specialist IRI or national centre for technology and industrial development.

4.1. Reserves.

The procedure for the detailed geological survey of the deposit, including drilling programme has to be designed for each individual deposit, taking into account the geological conditions, accessibility, existing exposures, etc. The aim of all such surveys is to establish a figure for the "proved" reserves. In addition tonnages for the "probable" and "possible" reserves are determined.

4.1.1. Definitions. The following definitions of these terms are those recommended by the Australian Institution of Mining and Metallurgy in 1972 and quoted by Royle. They apply particularly to metalliferous ores but can be used for non-metallics as well.

Proved Ore Reserves are those in which the ore has been blocked out in three dimensions by excavation or drilling, but include, in addition, minor extensions beyond actual openings and drill holes, where the geological factors that limit the ore body are definitely known and where the chance of failure of the ore to reach these limits is so remote as not to be a factor in the practical planning of mining operations.

Probable Ore Reserves cover extensions near at hand to proved ore where the conditions are such that ore will probably be found but where the extent and limiting conditions cannot be so precisely defined as for proved ore. Probable ore reserves may also include ore that has been cut by drill holes too widely spaced to assure continuity.

Possible Ore (not reserves) is that for which the relations of the land to adjacent ore bodies and for the geological structures warrant some presumption that ore will be found, but where the lack of exploration and development data precludes its being classed as probable.

4.1.2. Calculation. A three dimensional picture, or model, of the deposit has to be drawn, based on the topographic data, from available maps and field surveying, and the structural geological information recorded from surface exposures and borehole records. Based on the definitions given

- 14 - previously, the .....

previously, the volume of material in cubic metres, which lies within 'proved' and 'probable' (and 'possible' if relevant), is measured. For process calculations, the throughput of raw material is quoted in metric tonnes and the figures for the volumes of the reserves have to be converted using either measured bulk volumes of the rock as it is in the ground or else approximate factors, such as the following quoted by Boynton, are used :

	Kg/m^2	Lb/ft^3
limestone	2560	160
dolomite	2720	170
shale	2672	167

4.2. Performance

Analytical data such as chemical analyses and small scale laboratory tests do not prove that a particular deposit will be a suitable source of raw material. They only serve to eliminate the unsuitable materials, leaving the remainder which may, or may not, perform satisfactorily in a full scale process.

The problem is that in the small scale laboratory tests, using small static furnaces usually without adjustment of the atmosphere, and small moulds, etc. the raw material experiences different conditions from those of the factory where large rotary kilns may be in use and large moulds. There is usually some "scale-up factor" which becomes known after many tests and comparisons with factory results. The final choice of process equipment usually rests on proof, in a full scale trial. For example, to show that a clay will receive sufficient pugging by the action of the particular combination of primary crushers, rolls, screw mixers, etc. that has been proposed.

- 15 - The same .....

The same applies particularly to bloating of clays and shales. Small scale tests indicate those that don't bloat under the static furnace conditions and those that do. Conditions in a rotary kiln, sinter strand, etc. are quite different and only there can it be determined whether satisfactory bloating will occur under acceptable operating parameters, i.e. temperature, residence time, kiln length, atmosphere, etc.

The large bulk samples, usually many tons of material, have to be extracted from the deposit under close supervision to ensure that they are representative of the particular lithologies to be used and are correctly labelled. As mentioned earlier, full scale plant trials on raw materials should be easier to supervise, be cheaper and often quicker if they can be done using an appropriate plant that already exists in the country or else close by in a neighbouring country under a TCDC arrangement.

4.3. Cost Data.

In the full project proposal, an accurate figure is needed for the final delivered cost of the raw material to the plant and in a specified condition, i.e. either as dug or after certain preliminary treatment such as primary crushing and screening to a particular size range. The principle individual components of the figure for the final delivered cost, in currency units (US$ or Rupiah, etc.) per metric tonne, are as follows.

Land Cost, either as interest on the capital payments, if purchased, or the rental charges. The annual interest, or rent, is divided by the figure for the projected annual consumption of the raw material, in metric tonnes.

Royalty, or fee, payable for each cubic metre

- 16 - extracted. .....

extracted. If it is based on the volume as loaded on a truck, the bulk density will be less than when still in the ground and should be determined so as to convert realistically into US$ per metric tonne. The preferable system is to base it on weight and install a weighbridge upon which deliveries are monitored.

Mechanical Equipment Charges at the Quarry. These consist of the annual total cost of the following items divided by the projected annual raw material consumption :
interest on the original capital outlay, amortization charge, (to pay for future replacement of the mechanical diggers, primary crusher, etc., depreciated over the expected life of the equipment, usually taken as three years), maintenance, fuel, insurance, operators wages, etc. Alternatively, the mining, including taking off and conserving the soil, stripping the overburden, digging and loading the raw material, restoring the ground to agriculture, pretreatment and delivery of the raw material, may be contracted out with an agreed price per metric tonne.

Transport Cost, in US$ per metric tonne, from the quarry to the factory, including the various charges as listed above, but applied to the fleet of trucks, conveyor belt, aerial ropeway or other system selected.

5. LIMESTONES.

Limestones are usually of widespread occurrence, being the third most common rock type after shale and sandstone. Their main constituent is calcium carbonate, $CaCO_3$, usually as the mineral calcite. There are many different types, and

- 17 - classification .....

classification is either by reference to the mode of formation or the composition. The latter is either by degree of purity, i.e., content of calcium carbonate, or by the nature of the impurity present, e.g. argillaceous, phosphatic, etc. For use as raw material for cement and lime manufacture , the important criteria are content of calcium oxide, as the carbonate, $CaCO_3$, level of certain impurities, especially magnesia, MgO, and phosphate, P_2O_5, as well as silica, SiO_2, iron as Fe_2O_3, alumina, Al_2O_3, etc. which are present mostly as clayey or argillaceous material. For lime production, as well as road and concreting aggregates, the physical characteristics of the rock, such as porosity and hardness, assume greater importance than in the case of cement production.

Classification for economic purposes is based more on potential use for production of industrial lime rather than building material use which tends to have less stringent requirements of purity :

Ultra-high calcium limestone : more than 97% $CaCO_3$
High calcium limestone : more than 95% $CaCO_3$
High purity carbonate rock : more than 95% combined $CaCO_3$ and $MgCO_3$.
High magnesium dolomite : more than 43% $MgCO_3$.

Note that theoretically pure dolomite, $CaCO_3.MgCO_3$, contains 45.7 % $MgCO_3$ by weight.
In the ASTM definitions, C 119-50, the groupings based on content of $MgCO_3$ are as follows :

Calcite limestone contains less than 5 % $MgCO_3$.
Magnesian (dolomitic) limestone contains 5-40 % $MgCO_3$.
Dolomite contains more than 40 % $MgCO_3$.

5.1. Portland Cement Manufacture.

In the process for Portland cement, a controlled mixture of limestone or chalk, (or sometimes anhydrite)

- 18 - and clay or ......

and clay or shale is heated to a temperature, around 1350 - 1450° C, at which incipient fusion occurs to form a clinker. In this the lime (CaO) component has reacted with the alumina, silica and iron of the argillaceous (clay, shale) material to form new minerals, particularly calcium silicates. When the clinker is finely ground, with the addition of a small amount of gypsum (calcium sulphate) to control the setting time, the resulting cement can be hydrated, by the action of water, and harden due to the formation of cementitious calcium hydro-silicates.

If the raw materials had a high moisture content, a wet process for mixing was commonly used. That system has fallen out of favour with improved methods for mixing and regulating the mix in dry or semi-dry systems which have much better fuel economy. Portland cement is made in large capacity rotary kilns, often now combined with efficient pre-heating systems and capacities are normally around 1000 to 1500 tonnes of clinker a day, say 500,000 tonnes a year, from one kiln though larger kilns are being introduced.

Vertical shaft kilns were used successfully, before rotary kilns were introduced, and the coal or coke fuel was mixed with the raw materials. At present there is much interest in re-introducing vertical shaft kilns with oil or natural gas firing systems to produce between 20 and 100 tonnes of clinker a day.

5.1.1. Chemical Specification. The role of the limestone is to supply the calcium oxide component which is about 44 % of the total of the raw mix. This is equivalent to a minimum of 78 % of pure limestone (i.e. 100% $CaCO_3$) in the mix or rather more depending on the impurity of the limestone. The following table shows a typical raw mix and the clinker

- 19 - composition that ....

composition that would result from it, i.e. after driving off the carbon dioxide, etc. : -

	"Typical" + Raw Mix (from Lea)	Resulting Clinker
CaO	44.3 %	69.0 %
SiO_2	14.4 %	22.5 %
Al_2O_3	3.0 %	4.7 %
Fe_2O_3	1.3 %	2.0 %
MgO	0.6 %	0.9 %
$K_2O + Na_2O$	0.6 %	0.9 %
*L.O.I.	35.8	

* Loss on ignition, which includes CO_2, S^{--}, SO_4^{--} etc.

\+ This "typical" raw mix is quoted by Lea but in fact the resulting CaO level in the clinker is higher than usual for British cements, also quoted by Lea, and also the Silica Modulus turns out to be rather high as well : -

<u>Lime Saturation Factor</u> (LSF) $= \dfrac{CaO}{2.8\,SiO_2 + 1.2\,Al_2O_3 + 0.65\,Fe_2O_3}$

$= 0.99$

(The British Standard limits are 0.66 - 1.02)

<u>Silica Modulus</u> (SM) $= \dfrac{SiO_2}{Al_2O_3 + Fe_2O_3} = 3.37$

(typically 2.4 - 2.7 but may rise to over 4 in white Portland cements)

Alumina Modulus (AM) $= \dfrac{Al_2O_3}{Fe_2O_3} = 2.35$

(is between 1 and 4 in grey cements but can exceed 10 in white Portland cements)

- 20 - For comparison ......

For comparison, the range of composition for typical British cements, presumably including the added gypsum, and the typical compound composition ranges are :

	%
CaO	63.1 - 65.6
SiO_2	19.09 - 23.73
Al_2O_3	4.31 - 7.64
Fe_2O_3	1.59 - 3.59
MgO	0.56 - 1.23
K_2O	0.50 - 0.76
Na_2O	0.16 - 0.43
TiO_2	0.24 - 0.37
SO_3	1.00 - 2.59

Free lime	0.6 - 2.0
C_3S*	39 - 53
C_2S	15 - 34
C_3A	9 - 15
C_4AF	5 - 11

C = CaO, S = SiO_2

A = Al_2O_3, F = Fe_2O_3

The art of cement chemistry lies in balancing the various components to achieve fairly rapid development of strength by the cement without the risk of unsoundness developing in the concrete. Thus the proportion of CaO,(and hence of C_3S, or tricalcium silicate) is maintained as high as possible, to give a LSF close to 1 but without leaving more than 1.5 % of free lime in the clinker. (The presence of uncombined crystalline calcium oxide, tends to cause unsoundness in the concrete through expansive reactions, as is also the case with magnesia, mentioned later). The proportions of silica, alumina and iron, as the Silica and Alumina Moduli, are balanced so that the temperature of clinkering is neither too high so as to waste fuel nor drops too low so that there is fusion, or slagging, and greater risk of "rings" of clinker blocking the kiln.

If Low Heat Portland Cement or ASTM Type IV, is being made, the proportions of C_3S and C_3A, having the highest heats of hydration, are reduced by lowering slightly the amounts of Al_2O_3 and CaO in the raw mix. For Sulphate Resisting Portland Cement, i.e. ASTM Type V, the level of alumina is still further reduced so that no more than 5 % of C3A is formed, which is the crystal component most readily attacked, along with free calcium hydroxide, by sulphates dissolved in surface waters, the sea, etc.

Of most influence in eliminating the possible use of certain limestones, is usually the level of some minor components, in particular magnesia, MgO, and also phosphate. The various world standards for Portland cement limit the magnesium oxide content to 4 or 5 %. If the limestone, containing the magnesia, as crystals of dolomite, $MgCO_3.CaCO_3$, were making up say 80 % of the raw mix, then about 3 to 3½ % MgO is the maximum that could be tolerated in the limestone. More than that could lead to the cement being 'unsound' due to the presence of periclase crystals, MgO, which hydrate relatively slowly and cause disruption of the concrete as they do so.

Sometimes, as in Uganda for instance, the only readily available cement raw material is a phosphatic limestone. The presence of phosphate in a cement raw mix reduces the amount of tricalcium silicate in the cement by about 10 % for every 1 % of P_2O_5. The work of Nurse has enabled raw mix compositions to be calculated to produce satisfactory cements for mixes containing up to 2.0 - 2.5 % P_2O_5. The presence of fluoride in the raw materials, as fluorapatite for instance, can increase the tolerance for P_2O_5. In most

- 22 - Portland cements, ...

Portland cements, the content of P_2O_5 is only around 0.2 %.

Alkalis, i.e. Na_2O and K_2O, should be kept low to reduce the possibility of reaction occuring with alkali reactive aggregates such as opal, chert, etc. If reactive aggregates are suspected then the alkalis, expressed as $Na_2O + 0.658\ K_2O$, should not be more than 0.6 % of the cement, or about 0.4 % in the limestone.

5.1.2. Physical Specification. The physical nature of the limestone is not such a critical factor in cement manufacture as it is in lime production. This is because, apart from some small plants, all large modern cement factories use rotary kilns through which the raw mix is passed after undergoing considerable crushing and blending. The mining procedure and mix preparation process will depend, though, on the hardness of the limestone formation and the moisture content of the rock. Thus, whilst some massive crystalline limestones will have to be blasted with explosives, some chalky coral limestone beds can be dug directly by mechanical shovel. If the raw materials have a low moisture content when dug, their blending can be done in the dry state after crushing, i.e. the dry process, so as to achieve better fuel economy. Conversely, where the limestone had a high water content, as in say a porous chalk formation, the crushing and blending was done by the wet process, as mentioned earlier. The special situation with the chalk and clay used for the 4 million tonne a year cement factory at Northfleet, UK, made it necessary to use the wet process there. With the introduction of the semi-wet process, with an energy consumption only about

- 23 - 70 % of the .....

70 % of the wet process, it is possible to use, much more economically now, raw materials having relatively high natural moisture contents which can be prepared without difficulty only by wet methods.

5.1.3. <u>"Ideal" Limestones</u>. Very seldom is it possible to find a raw material that has exactly the composition required for cement production and normally clay or shale, as well as siliceous sandstone and iron-rich sand, have to be added to adjust the composition.

The Jacksonberg "cement rock" formation, in the Lehigh River area of Pensylvania, is a dark grey to black argillaceous limestone containing only 65 to 70 % of calcium carbonate and has been used for Portland cement manufacture since 1875.

A chalk marl formation near Cambridge, England, has an analysis approaching so near to the correct proportions that at one time "naturel" cement was made from it without the mixing of any adjusting components such as clay. Its composition was :

Calcium carbonate : 76.6 %
Silica : 15.7 %
Alumina : 4.2 %
Iron oxide : 1.9 %
Magnesium carbonate : 1.3 %

It is a fallacy, therefore, that only high calcium content limestones should be sought for cement manufacture projects. It seems probable that in some developing countries deposits of relatively low $CaCO_3$ content being rejected could be used for cement manufacture without much difficulty.

- 24 - 5.1.4. <u>Reserves</u> .....

5.4.4. Reserves. Before being able to establish a modern, large cement factory, there have to be proven reserves of raw materials available for at least 40 years, and preferably even longer, say up to 100 years. In the late 1970's, the normal production capacity for a new cement plant in a developing country was of the order of 1 million tonnes a year. This was usually by having two rotary kilns each producing 1500 tonnes a day of cement clinker. For purposes of calculation of reserves required, the average production period for a kiln in a year is taken as 330 days, which allows about 30 days for maintenance, especially replacing of the refractory, and occasional breakdowns, etc.

If the CaO content of the cement clinker is taken to be 65% and if a pure limestone, containing 100 % $CaCO_3$, is available, then 1 tonne of Portland cement clinker would require about 1.16 tonne of the limestone. But the limestone may contain about 90 % $CaCO_3$ in which case for a production life of 40 years at 1 million tonnes a year, the reserves of limestone required will be :

$$1 \text{ million X } 40 \text{ years X } 1.16 \text{ X } \frac{100}{90} =$$

$$51.6 \text{ million tonnes.}$$

Measurement of the density of the limestone from cores taken from boreholes enables the in-ground volume of this tonnage to be calculated. A solid limestone will weigh around 2560 kg/m^3, or 160 lb/ft^3. Hence the volume of limestone required is:

$$51.5 \text{ million X } \frac{1}{2560} \text{ X } 1000 = 20.1 \text{ million cubic metres.}$$

- 25 - In other ....

In other words, the geological prospecting team has to prove the existence, in readily accessible form, of a body of limestone say 2000 m long by 1000 m wide by at least 10 m thick.

As it is much less costly to increase the capacity of an existing cement plant, which already has the required facilities such as access road, laboratory, workshops as well as trained personnel, than to build a new plant of the same capacity in a virgin area, it is usual to increase the capacity of the original plants in a country provided the required reserves of raw material exist there. Therefore, when planning a project for a new factory which is to serve a large area, there is much to be said for establishing it on or close to a limestone deposit that has many times the reserves thought to be required initially. However, raw material considerations, though of paramount importance, have to be considered in the light of other important factors, especially the proximity of the market to be served and the location of the cheapest transport routes.

It is of great economic importance, in the selection of both the limestone source and the factory site for cement and lime manufacture, that the plant be as close to the raw material source as possible. Normally, the limestone will be hauled to the plant by truck but savings in costs are made if a conveyor belt system can be used. Up to 44 % of the limestone being transported is valueless as it consists of combined carbon dioxide, CO_2, which is burnt off as gas in the kiln. Hence cement and lime plants are often

- 26 - located in .....

located in relatively remote areas, where the limestone exists, as well as for environmental reasons, and it is more economic to transport the denser cement, or preferably the unground clinker, to the consuming centre for direct use or grinding in a separate milling plant.

5.2. Lime Production.

Before the energy crisis, it was the custom in certain countries having relatively low cost oil or gas, such as the United States, to use rotary kilns for lime production. These had the advantage of easier control and hence a higher quality product, (especially lower sulphur content), high production capacity and a smaller, though narrower, range of stone feed size. Apart from locations such as Qatar, where there is low cost fuel available and where rotary kilns have recently been installed for lime making, it will usually be the shaft kiln that is specified in future, in one of its many designs, because of its better fuel economy.

5.2.1. Chemical Specification. In the industrialized countries, lime is used much more for industrial purposes, such as steel making, chemical processes, etc., and much emphasis is put on purity, i.e. high CaO content. Such lime is white in colour and may be used, of course, for traditional building purposes such as in mortars for masonry as well as white wash, etc. But, with the advent of relatively cheap cement, the small lime plants supplying building grade lime, which though perfectly adequate for mortars was not so pure as industrial grade lime, gradually went out of business. Their costs were high because of the high wage bill for continuous shift operation on

- 27 - a relatively .....

a relatively small production plant in often rather dirty working conditions. It is now difficult or impossible to purchase these grey hydraulic or semi-hydraulic limes in the industrialized countries.

Possibly because of this, it has come to be thought in the less developed countries that lime has to be white to be any good as a building material. This is not so and there is a need to ensure that suitable impure, or clayey, carbonate rocks are not rejected in planning projects for "building lime" production, i.e. for use in mortars, renderings, soil stabilization, etc., and also in production of blocks. These processes involve the reaction of lime with silica and are not necessarily harmed by the presence of alumino-siliceous material in the burnt limestone.

In general, there can be up to about 10 % silica and 5 % alumina in the form of dispersed clay mineral matter in the limestone.

Magnesia, MgO, may cause unsoundness in the product due to its later hydration and cause popping of a plastered surface. These dolomitic limestones can be used if the burnt limestone, i.e. quicklime, is slaked in water for a longer period, even 14 days, before use in a mortar. Any tendency to unsoundness is simply checked by making the freshly hydrated quicklime into a thick paste with water and smoothing it out to a flat surface, with a spatula, in a saucer or watchglass. After two weeks left to stand in the laboratory, the presence of 'pop-outs' on the surface indicates unsoundness.

- 28 - 5.2.2. Physical .....

5.2.2. Physical Specification. Although the content of calcium carbonate is a main factor in the selection of raw material for lime manufacture, the physical nature of the rock is usually of much more importance than is the case with cement plants. This is because it is more usual to make lime in vertical shaft kilns. As the shaft will be filled with limestone, it is essential that sufficient space be maintained between the lumps of rock to allow a free upward movement of hot gases through the kiln. Therefore, the rock must not break up in the kiln and block the gas flow.

Soft or chalky limestones, which are often rather dolomitic as well, are usually not suitable as they produce too much powder which clogs up the kiln. Thus it is necessary to seek a uniform and fairly hard limestone which will not decrepitate or break up during its passage down the kiln. In batch kilns, where there is little or no movement of the raw material during firing, the problem may not be so acute. It is difficult to predict whether a particular limestone will decrepitate and so nearly always a kiln trial, possibly by examining the state of the product from existing traditional kilns, is necessary. In general, crystalline limestones having a large crystal size have this tendency to break up during calcination.

Uniform porosity and size of feed is necessary if the limestone is to be burnt evenly and not overburned or underburned. In regions such as the Andes and in Indonesia, where there has been recent volcanic activity, there are deposits of travertine, an often quite pure calcium carbonate rock,

- 29 - precipitated .....

precipitated from hot springs, but having very variable porosity. Although they can be used to produce lime, there is usually much wastage due to the denser parts being underburnt and the porous pieces being overburnt to form unreactive lime which slakes very slowly with water and is of little or no use.

Shaft kilns can take a feed size up to 20 cm, (8 in). A regular round shaft kiln of capacity 50 - 500 tonnes a day would take a feed of 6.5 to 20 cm size (2½ to 8 in), whilst a double-inclined rectangular shaft kiln would need a smaller feed size, i.e. 1.3 to 6.5 cm (½ to 2½ in.). In traditional batch kilns the limestone lumps are larger at the base, being around 25 cm, (10 in.), and reducing to around 7 cm (2¾ in.), at the top. In rotary kilns, also, the feed size is fairly rigidly regulated to obtain a more uniformly burned product and each design of kiln, often also with a preheater system of grate or shaft type, will have a specified feed size. This ranges from stone size of 12 mm X 20 mm, (½ in X 3/4 in.), for a 300 tonne a day, 40 m long by 3 m diameter, kiln with contact cooler, to 25 mm X 60 mm, (1 in X 2½ in.), for a 640 tonne a day, 145 m by 3.5 m, kiln with contact cooler.

5.2.3. **Reserves.** In calculation of the volume of reserves necessary for establishing a lime plant, there is an important factor which is in addition to the number of years over which the plant will be depreciated and the in-ground bulk density of the limestone. Unlike cement processing, the feed to a lime kiln has to be within close size limits to ensure even burning. Hence, there has to be -

- 30 - careful control .....

careful control of the blasting in the quarry and the crushing so as to reduce to a minimum the amount of undersize material produced. Much of this waste is unavoidable and it is reasonable to assume that it will amount to as much as 50 % of the rock in the ground, thus doubling the reserves that have to be proven. Often, the undersize limestone can be utilized, depending on its quality, as concrete aggregate, in asphalt road surfacing, as fine filler, after grinding, for plastics and rubber, or else as loose fill material.

A minimum of 20 years supply of limestone is necessary. As with cement plants, the guarantee of a much longer period of operation at the selected site is highly desirable. In the calculation of the limestone reserves needed, for a particular output of quicklime or hydrated, i.e. slaked, lime one uses the following values for their equivalent proportions :

limestone, pure, $CaCO_3$	100.1
quicklime, CaO	56.1
hydrated lime, $Ca(OH)_2$	74.1

Example :

Assuming that there is a project to produce 100 tonnes a day of quicklime. If all were hydrated, the quantity of hydrated lime produced would be :

$$100 \times \frac{74.1}{56.0} = 132.3 \text{ tonnes a day.}$$

Assuming 50 % loss of limestone during mining and crushing*, and an operating period of, say,

- 31 - 30 years, the ....

---

* Making allowance for the inevitable loss of some stone, the lime industry in the U.S.A. has standardized its calculations on 2 tons of stone for 1 ton of quicklime.

30 years, the reserves needed are :

$$100 \times \frac{100.1}{56.0} \times \frac{100}{100-50} \times 330 \text{ days}^{+} \times 30 \text{ years} =$$

$$3.54 \text{ million tonnes.}$$

At a density of 2560 kg/m^3, the volume of reserves is :

$$3.54 \text{ million} \times \frac{1}{2560} \times 1000 = 1.38 \text{ million } m^3.$$

[+] As with a cement plant, the usual production period in a year is taken as 330 days for this type of calculation, to allow for breakdown time and maintenance.

The comments on locating a cement factory within easy access to the deposit of limestone apply also to lime plants. Ideally, the kiln should be situated as close as possible to the quarry or mine, it being more economic to transport the product, as quicklime or hydrated lime, than the limestone.

5.3. Aggregate for Concrete.

In many developing countries, it is not realized that crushed limestones can be excellent aggregates for concrete production as well as for bitumen-coated road aggregate, or 'asphalt'. The reasons for this misapprehension are several.

Firstly, it will usually have been the tradition to use river gravel as that can be used after only crude processing through a sieve and crushing of the oversize material. Also, when seeking sources of rock to crush, it was logical to use similar rock types to those found in suitable river gravels, usually the hard, igneous or metamorphic rocks. Limestones vary considerably in their

- 32 -. hardness and .....

hardness and porosity, sometimes being rather soft and crumbly. Consequently, an engineer responsible for specifying an aggregate may tend to be prejudiced against all limestones. Finally, the local cement manufacturing interests claim the deposits of accessible limestone, sometimes far exceeding their foreseeable future requirements. Together with the officials responsible in the mining ministry for granting mining concessions, they may seek to disallow extraction of limestone for what they would consider the relatively lower grade use as aggregate for concrete or road surfacing.

In fact, it is possible to obtain higher concrete compressive strengths with certain limestones than, for instance, with granite or gabbro. Other concrete characteristics such as durability can be high as well. The better limestones have a low water absorption, up to 1%, and high crushing strength, 200 to 250 kN (20,000 - 25,000 kgf), by the ten percent fines test. Somewhat lower quality concrete will, in general, result from using limestones having higher water absorption and lower crushing strength. Often these are the dolomitic limestones.

It is probable that limestones have a more suitable surface to which cement paste can adhere, compared to granite for example. A very thorough investigation of the characteristics of crushed rock aggregates from 24 separate sources, of which 10 were classified as limestones, and the rest granites, gabbro, gritstone, hornfels, porphyry and quartzite, and the concretes made from them, has been carried out at the Building Research Establishment, England by Teychenne.

A further factor in favour of limestone as aggregate in developing countries is that only seldom does the

- 33 - concrete have to ....

concrete have to withstand cycles of freezing and thawing and so the rather porous nature of some limestones is less of a risk in reducing the durability of the concrete, than it would be in Europe or N. America.

In considering concrete aggregates, it should not be overlooked that much construction work requires only fairly moderate compressive strengths. This is particularly so in the case of concrete blocks for wall construction to single storey height. More important in such uses are factors such as the workability of the mix obtained, the 'green', i.e. uncured, strength of the block to withstand handling after moulding and the degree of shrinkage on drying. The minimum average compressive strength of such blocks can, in many cases, be only 3.5 N/mm^2, (35 kgf/cm^2 or 500 lbf/in^2). On the other hand, cast in situ concrete will usually have to exhibit strengths of 5 or 6 times this amount.

In summary, then, it is important to consider what the requirements of the concrete are and, by suitable trial mixes and strength tests, see whether the locally available limestone can be used in place of the more expensive gravel or crushed igneous rock from further away.

6. NATURAL POZZOLANAS (TRASS, ETC.)

This chapter includes all those naturally occurring deposits of volcanic origin that exhibit some degree of pozzolanic activity and which may be used with lime and/or cement for the making of blocks, cements, mortars and concrete mixes generally. Pozzolanicity is a property sometimes shown by such volcanic materials as ash or tuff and pumice, as well as by diatomite and artificial pozzolanas such as crushed bricks, burnt clay or shale and fly ash. These

- 34 - contain siliceous ....

contain siliceous constituents that can react with lime at moderate temperatures in the presence of water and form a durable cementing material. Much use had been made of such materials in construction before the introduction of Portland cement in the early 19th century

Except in China, the usual policy has been to manufacture cement from only a few very large units to achieve economies of scale. This, though, has increased the transport component in the price of cement to the small consumers in regions far from the cement factory. There is likely, then, to be an increasing interest in future in the utilization of natural pozzolanas and lime for wholly or partly replacing expensive cement. This will be the case particularly in the developing countries many of which are in regions of active or recent volcanism. They also have projects such as irrigation schemes, including dams and canals, harbour construction and also ordinary building construction such as brickwork in which the particular properties of mortars and concretes incorporating additions of pozzolana can be highly beneficial, both in performance and cost.

Deposits of pozzolana, such as trass, can be assessed from two viewpoints :

i) as a source of pozzolana. This is when the natural material is mixed with sand and some lime or cement to form a mortar, or else is ground up and blended with Portland cement clinker, at a grinding plant,

ii) as a pozzolanic aggregate to mix with lime and make blocks (in Indonesia, 'batako' blocks). In this case not only is the degree of pozzolanic activity significant but also the size grading.

6.1. Evaluation in the Field.

The assessment of a deposit of trass or pozzolana is difficult or impossible by visual inspection in the field. Virtually all that can be achieved during field work is to recognise material that may be pozzolanic, because of certain features it exhibits, and then await the result of tests on the samples. No precise rules can be laid down and one has to approach the subject with a completely open mind. The following general points can be mentioned.

6.1.1. Volcanic. The deposit will usually exhibit, but not always, the geological characteristics of having been deposited from a volcano. Normally it will be in the form of a layer, either horizontal or closely following the topographic slope of the surface. It may contain fine ash, pieces of pumice, obsidian and other glassy fragments and possibly larger rocks or 'bombs'.

6.1.2. Amorphous. The structure of a major proportion of the material, when viewed with a hand lens, should appear glassy or amorphous, because macroscopic crystalline grains have little or no ability to react with lime at ordinary temperatures. This does not mean that the degree of pozzolanicity can be predicted in this way. There should not be a large proportion of hard rock debris as is the case with some volcanic breccias or agglomerates. The need to separate this unreactive material from the finer matrix will make it less economic to exploit the deposit, unless there is a local demand for the hard rock as fill for foundations, etc.

6.1.3. Colour It might be thought that the lighter coloured volcanic deposits, usually having highe:

contents of silica and alumina and hence more 'acidic', would have higher pozzolanic activity than darker, more 'basic' material. However, quite dark, brownish or grey trass deposits are used successfully for block making near Bandung in Java. It is possible that the strength of the blocks there is enhanced by a favourable grading of the trass giving good compaction.

6.1.4. <u>Freshness</u>. The material should be as fresh as possible; that is, have retained as far as possible its original mineralogical character which it had when first ejected from the volcano. If the material has been exposed to the weather by having overlying sediments stripped off through denudation, then much of the pozzolanic activity of the trass will have been lost. The active siliceous or alumino-siliceous component will have reacted already with alkali and alkaline earth salts in percolating ground waters.

Many deposits which occur on the slopes of volcanos of recent activity have been eroded and re-deposited by floods of rainwater and rushes of mud coming down the mountain. In Ecuador these form the deposits around Quito known as 'cangagua' and in Java the 'lahar' deposits. It general, it can not be expected that these will have retained very much of their original activity but, as always with trass deposits, they have to be tried in mixes with lime and tested for compressive strength before being ruled out of consideration.

6.1.5. <u>Uniformity</u>. This is a major requirement when the material is to be used as an additive for grinding in with Portland cement clinker to make Portland Pozzolanic Cement (PPC). The PPC will often

- 37 - have to compete ......

have to compete with ordinary Portland cement (OPC) to gain acceptance by the building and civil engineering contractors and also by small users. If variation in quality of the PPC, either in strength development or setting time, etc., occurs, due to variation in the pozzolanic additive, adverse publicity will occur which may take a long time to overcome. Hence, deposits should not only appear uniform, both laterally and with depth, but also have been shown to have little actual variation in pozzolanicity in samples taken from boreholes throughout the part of the deposit required to be used. Minor variations can be accomodated by blending at the stockpile beside the grinding plant. For the users of smaller quantities, such as blockmakers, uniformity is also most desirable but any changes can usually be dealt with readily by adjustments to the process.

6.1.6. <u>Location</u>. Transport costs have become a much more significant part of building material projects since 1973. The factor that usually most fluences the raw material cost delivered to the factory is the cost of transport from the deposit. Pozzolanic materials are often located on the slopes of mountain ranges and remote from cement plants or other centres of demand. It is often not practicable to use such deposits, situated 50 or 100 km or more away, and accessible only by tortuous mountain track,or even without ready access until a road has been built. Such distances require a large fleet of trucks and supplies may fail to maintain the stockpile at the factory in bad weather. Long distance transport of pozzolana can be feasible if both the deposit and the cement plants are located close to deep water, either beside the sea or on a navigable river. Cement clinker made on the mainland of Spain is shipped to the Canary Islands for grinding there with volcanic pozzolana.

6.1.7. Accessibility. Apart from distance by road, there are factors such as the final access to the exposure, which may require a road to be constructed for the last few kilometres, construction of bridges, presence of growing crops, houses, graveyards, and, most important, the nature and thickness of the overburden. It is common, as in Java, for trass deposits to be covered with several metres of clayey soil. At exposures revealed on a hill side or river cutting, the overburden thickness increases as the extraction proceeds into the hill, because normally the dip, if any, of the trass layer is less than the slope of the surface. Eventually, horizontal adits have to be cut to continue extraction by underground mining which not only is more dangerous, of course, but is unpleasant and difficult for the miners due to the moisture from the trass causing high humidity.

6.2. Laboratory Evaluation.

Although it has been usual to carry out a chemical analysis of deposits of pozzolanas, such as trass, for SiO_2, Al_2O_3, Fe_2O_3, CaO, etc., the results will provide no basis for estimation of its activity. Even the test based on the rate of absorption of lime from a solution of calcium hydroxide is no test for the practical value of the pozzolana in use though it may have some value

- 39 - for rapid ....

for rapid distinction between material that is active and that which is probably not.

Likewise, the measurement of the increase in volume of solids produced when pozzolana is put in a solution of lime in water, called the swelling volume test, has been shown to have little value.

Assessment of pozzolanas is most reliably achieved by means of physical tests, carried out on standard mortar mixes using compressive and/or tensile strength determination after specified curing times. In addition, rate of hardening of these mortars is used, following a procedure similar to that for the setting time of Portland cements, i.e. the Vicat needle method. Fineness of the pozzolana and the temperature during curing greatly affect the results. Logically, the fineness chosen will be the same as that when the pozzolana is used in practice, i.e. either 'as dug' if fine enough for direct use in a mortar mix or block, or ground to a fineness comparable to that of Portland cement, say 3500 cm^2/g, if it is to be milled with Portland cement clinker to make Portland Pozzolanic Cement for example.

There are various standard test methods including German, American, Indian and Indonesian, and examples of the compressive strengths achieved by various pozzolanas and some details to show the characteristics of the test are given below.

6.2.1. <u>German Procedure</u>. Tests to the German trass specification : DIN 51043(1931) use mortars of 0.8 : 1 : 1.5, hydrated lime : pozzolana : standard sand proportions.

- 40 - Pozzolana ....

Pozzolana	% residue on 170 mesh sieve	Compressive Strength kg/cm²	
		7 days	28 days
Italian	33.8	98	189
Trass	35.5	78	118
Moler	49.2	28	69
Pumice	29.2	35	103

The maximum residue on the 900-mesh/cm² sieve is 20 %. The mix is gauged with 11 - 12½ % water. This rather dry mix is compacted with the Boehme hammer machine. The specimens are cured in moist air at 17 - 20°C and in water at the same temperature. The minimum requirement on compressive strength is 45 kg/cm² at 7 days and 140 kg/cm² at 28 days. (The tensile strength requirements are 5 and 16 kg/cm² at 7 and 28 days respectively.)

6.2.2. American Procedure. The ASTM specification for pozzolanas is C593 - 69. In the test for pozzolanic activity index with lime the mix is 1 : 9, hydrated lime : graded sand, plus an amount of pozzolana equal to twice the solid volume of the lime. The mortar is cured at 23°C for 24 hours then 6 days at 55°C with the last four hours of which cooling to 23°C. The compressive tests are on 2 X 4 inch (5 X 10 cm approx,) cylinders.

6.2.3. Indian Procedure. The Indian Standards Institution Specification for lime-pozzolana mixture is IS 4098-1967. The compressive strength requirements to meet the LP 40 grade are 20 kg/cm² at 7 days and 40 kg/cm² at 28 days. The mix is 1 : 2 : 9 , lime : pozzolana : sand.

- 41 - 6.2.4. Indonesian ..

6.2.4. Indonesian Procedure. The Indonesian Standard test method for trass is in NI - 20. A mix of 1 : 2 : 3, lime : pozzolana : standard sand by weight, is moulded and stored for 1 day in moist air and 13 days in water at room temperature. Three qualities are distinguished from the compressive strength values :
I : 100 kg/cm^2. II : 75 - 100 kg/cm^2.
III : 50 - 75 kg/cm^2. This NI - 20 Standard requires the test sample to completely pass a 2.5 mm sieve and hence is assessment of a relatively fine pozzolana for use in mortars. The Indonesian requirement for the compressive strength of 1 : 5 , lime-trass hollow blocks after 28 days storage in air at ambient temperature, is 25 kg/cm^2 for non-load-bearing blocks and 50 kg/cm^2 for the load-bearing type. In this case, the trass, besides contributing as a pozzolana, also acts as an aggregate and maximum size of 10, 15 or even 20 mm can be accomodated depending on the thinnest wall dimensions of the hollow blocks to be manufactured.

6.3. Pozzolana in Concrete.

When pozzolana is used in concrete, either,interground with Portland cement clinker to form Portland pozzolanic cement or added during mixing of the concrete as part replacement for up to 40 % of the Portland cement, the strength development is slower compared with the normal mix. With a satisfactory pozzolanic additive, the compressive strength of a 1 : 2 : 4 : 0.6 concrete with 30 % substitution of pozzolana for Portland cement, should have a strength after one year that is the same as or slightly higher than that of the normal mix. In addition, there will be greatly improved durability against attack by acidic and

- 42 - sulphate bearing ...

sulphate bearing waters, as well as lower heat of hydration, thus making these concretes particularly useful for marine construction such as docks, as well as massive foundations and dams and also irrigation canals.

Acknowledgement

This paper was first published in December 1978 as Technical Paper No.17 of the UNDP/UNIDO Project INS/74/034, 'Assistance to the Industrial Development of Building Materials Manufacture'. The author was then UNIDO Adviser on Raw Materials Assessment co-operating with the Directorate of Building Research and the Ceramic Research Institute in Bandung, Indonesia.

SOME REFERENCES.

1. The Chemistry of Cement and Concrete. By F.M. Lea. Edward Arnold (Publishers) Ltd. London. 3rd Edition, 1970.
2. Geology of the Industrial Rocks and Minerals. By Robert L. Bates. Dover Publications Inc. New York, 1969.
3. A Description of the Manufacture of Portland Cement. By Gilbert Davis. Eastwoods Ltd., England. 1962.
4. The Use of Crushed Rock Aggregates in Concrete. By D.C. Teychenne. Building Research Establishment, Department of the Environment, England. 1978.
5. Guide to the Geological Investigation of Rock Deposits for Building Material Production. Tech. Rep. No.15. By Neville R. Hill. UNIDO/UNDP Project INS/74/034, Bandung. February 1977.
6. Industrial Minerals and Rocks. Ed. by S.J.Lefond. Society of Mining Engineers of AIME. 4th Edition. 1975.
7. Portland Cement in the Making. Publ. by Cement and Concrete Association, England. October 1977.
8. Report by the Joint Committee on Ore Reserves. Australian Inst. Mining and Metallurgy and Austr. Min. Ind. Council, Victoria. April 1972.
9. Factors in the Selection of a Site for a Factory for Building Material Production. Tech. Paper No.13. By Neville R. Hill. UNIDO/UNDP Project INS/74/034, Bandung. Dec. 1977.