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Technical report: Limestone as raw material for the cement industry*

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

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*This document has not been edited.

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Introduction

Carbonates are considered as the principal raw materials applied in cement "clinker" manufacturing. Carbonates include the raw materials formed mainly of calcium carbonates e.g. limestone, chalk, marble sea shells, marly limestone, carbonate sludge of paper, sugar and fertilizer industries.

Beside the carbonates (calcareous materials) as a main component required for the cement raw mix alumina and limesilicate minerals "clay, soil, shale, slate, volcanic rocks, fly ash, wollastonite rocks, slag have to be mixed with and in some cases with some more additives to form clinker complying with standard specifications after carrying out blending, prehomogenization and burning the raw meal in cement rotary kilns.

Calcareous material (carbonates) supplies calcium oxide (CaO) to cement clinker. CaO is contained in all 4 main minerals which constitute clinker. The calcareous materials required for cement "clinker" manufacturing is governed by some specific chemical as well as physical properties. Of course, it is necessary for the chemical composition of limestone to be within proper range. Furthermore, it is necessary for limestone to have high grindability and good burnability.

There are some facts regarding the chemical composition of a calcareous material which have to be stated as follows:

1) Chemical composition of calcareous material

Limestone which consists mainly of $CaCO_3$ has some amount of impurities such as SiO_2, Al_2O_3, Fe_2O_3 and MgO. The fewer the impurtiies of limestone, the better it is. The first requirement of limestone for cement is that its chemical composition is stable. The more its impurities increases, the more its chemical composition fluctuates.

It seems also that much impurities cause poorer clinker burnability.

Chemical component of limestone affects cement production as follows:

A) MgO

MgO is a harmful component which is most severely restricted in limestone for cement production. If MgO in clinker is within the proper range, it is contained in clinker in the from of solid-solution with C_3S or C_4AF and improves the burnability of clinker. In other words MgO is combined up to 2% by weight with the main clinker phases; beyond that amount it appears in the clinker as free MgO mineral (periclase). However, when MgO content is beyond the limit of solid-solution, free magnesium oxide crystals (periclase) appear. The periclase crystals react with water slowly and the volume of periclase crystals increase on hydration due to the formation of brucite mineral
($Mg(OH)_2$) : $MgO + H_2O = MG(OH)_2$. This reaction proceeds slowly, while the other hardening reactions in the concrete are already concluded. Since the $Mg(OH)_2$ (Brucite) occupies a larger volume than the MgO (Periclase) and is formed on the same spot where the periclase particle is located, it can split apart the binding of the hardened cement paste (concrete). So expansion crack is generated in hardened concrete (magnesia expansion).
Therefore, most of the Standard Specifications specified that MgO content in portland cement be under 4.0% - 5.0%
From the consideration on limestone unit consumption and MgO content from other materials, it is feared that cement will not satisfy Standard Specifications in case MgO content in limestone is more than 3.5%.
In case of low MgO limestone, limestone with high MgO content may be added to improve burnability and cement colour "not more in average than 3.5%" as it is known that MgO has flux effect.

B) CaO

The unit consumption of limestone for cement production is within the range of 1,000 to 1,350 kg in most of the cement factories depending mainly on CaO purity of limestone, and secondary on the kind of cement and chemical composition of clays.

High purity limestone contains such small impurtiy that variation is small.

As much impurity causes much variation to chemical composition of limestone,accordingly it is necessary to control the quality of limestone.

SiO_2 and Al_2O_3, considered as impurities in limestone, are not of special problem as these elements are also necessary constituents of clinker. Limestone which is rich in SiO_2 and poor in Al_2O_3 may sometimes require high alumina corrective material such as expensive bauxite depending on the type of clayey material.

2) Grindability and reactivity of calcareous material

Generally speaking the proportion of limestone in cement raw meal varies between 75 - 80%. Therefore, its grindability seems to affect remarkabely the grindability of raw material in the raw mill. It is not clear technologically which limestone has the best grindability. Generally it is said that limestone of large crystalline particle has better grindability. That is, coarsely crystalline limestone shows better grindability than finely crystalline one. Furthermore, the grindability of limestone which has much impurity is affected by coexisting minerals to some extent.

The size of crystal in limestone and kind and amount of impurity affect the burnability of clinker. It is said that microcrystalline limestone has lower decarbonation temperature and better reactivity with clay than macrocrystalline one.

NORMS AND PRE-REQUISITES FOR SETTING UP NEW CEMENT PROJECT OR EXTENDING EXISTING PRODUCTION LINES

Cement industry is dependent of natural resources like limestones and clays; limestones are the basic raw material applied in cement manufacture. Therefore, before setting up any cement plant, it is essential to investigate the available raw material deposits from the quality and quantity points of view and ensure their proper exploration. There are many examples where cement plants in many countries have struggled after their establishment due to inadequate attention paid to above criteria.

Development of cement industry involves huge capital and substantial participation of men and materials. The feed materials like minerals and rocks which constitute the cement raw mixes "meal" of a given cement plant, require effective prospecting and exploration work suitably designed for the deposits of raw materials necessary for the cement industry.

The ultimate economic viability of cement industry, which is very capital intensive, depends on the quality and quantity of the usable raw materials. Accordingly, there is a great need for appropriate and optimum quantum of exploration work for assessing the involved parameters with a certain degree of reliability in order to minimise the risk in the investment. The important determinants of economic viability of any cement plant are quality, quantity and minability of relevant natural raw materials; proper assessment of the above constitutes the techno-economic basis for a decision to set up a cement plant.

There is no doubt that investigation, prospection and exploration of raw materials are fairly expensive operations. Therefore, these operations have to be so optimised that the eventual exploration of the deposit becomes much feasible and remains very profitable for the life-time of the plant. The important aspects of prospection, exploration, testing and reserve estimation of limestone depend on the grade of limestone available.

The cement requirement for some decades and, therefore, the necessary minimum size of the raw material deposits is to be chosen from the previously carried out geological investigations i.e. known mineral occurance. The Governmental Geological and Mining Departments "based on the required/acceptable chemical and physical properties of the raw materials." Explorations must be concluded as soon as the necessary information on deposits or part of them required for industrial purposes has been procured.

Based on the shape and extent of deposits, conditions of deposition, lithologic and compositional variation, geological age, structural disposition, topographic placement, tectonic features, etc, the grade of limestone deposits can be classified generally as: (1) Simple; (2) Complex; and (3) Intricate.

While "simple deposits" are large, continuous, bedded, horizontal to gently dipping, undisturbed and uniform in quality, "complex deposits" are moderate to steeply dipping, gently folded, consistent, more or less simple but with frequent intercalations, variable thickness, detached and lenticular, folded or structurally disturbed. "Intricate deposits" are complicated, highly folded, dislocated, irregular in shape or those which are intensely interbedded deposits with clay or shale or show extremely varying form, thickness or assay values.

A pre-requisite for setting up a new production line or cement plant shall be to ensure that the measured reserves, taking into account mining losses of 15% and shortfall due to reserve estimation error of 15% amounting to approximately 30% of the actual limestone requirement, is enough for at least 30 years together with sufficient recoverable quantity of indicated reserve for at least 20 years.

The deposit must fill cement industry's particular needs. In essence, the work must be done for this specific purpose and by influence - according to a specific plan. The plan is called an exploration programme; it begins with a need for minerals or rocks and if successful, leads to newly discovered source of raw materials for the cement industry. The plan, now carried out as a prospect evaluation, is intended to end with a recognized economic raw material deposits.

The exploration programme of raw material deposits consists of three sequential phases: (a) Reconnaissance; (b) Detailed Prospecting; and (c) Detailed Exploration. In addition to these phases, there shall be another phase designated as "Exploratory Mining" that will run concurrently with the mining of a deposit.

Definition of phases and their relation with categories of reserves:

Phase I: Reconnaissance and regional exploration

This pase refers to exploration involving collection of available geological literature, studies, reports, traverses and to choose a sizeable area where the raw materials required for manufacturing of cement are available. The size of the exploration area is between a couple of hundred to several thousand square kilometers. The work will primarily concentrate on economic geology including simple exploration work and is very time-consuming. The field work is normally carried out under primitive conditions. Collection of surface samples and rapid survey of infrastructural facilities, coupled with study of available literature is foreseen for this phase that should yield sufficient information for estimating inferred reserves which could be converted, with progressive inensification of exploration, into required quantities of indicated and measured reserves. The exploratory work in this stage should enable the entrepreneur to select a suitable area in order to apply for a prospectus licence. It is hard on the team and the machines and requires special equipment and experienced personnel.

Phase II: Detailed prospecting

This kind of exploration is limited to an area of some square kilometers approx. 25 kms or blocks in which a deposit is expected to be located or has been found and that would yield the required quantity of indicated reserves.. The dimensions and the contents of the deposit now has to be defined. Wherever posible the investigations normally start with geological mapping (a key plan of the area on 1:4000 scale should be prepared), a sampling of outcrops and simple prospecting work (trenches, drifts and small shafts.) On rare occasions these explorations are sufficient for assessing a deposit.

In most cases it is necessary to drill in order to explore deep level parts of the deposit. Drilling should be undertaken at suitable intervals depending upon whether the deposit is simple, complex or intricate. Drilling is expensive and must be planned and carried out carefully. Usually, it can be recommended to contract this task out to a specialist firm under the regular supervision of one of the client's own consultants. Frequent contacts between customer and contractor are generally useful for both parties. It is normally necessary to have a field laboratory for sample preparation and for simple daily analyses and the services of a main laboratory which has been equipped for this kind of raw material explorations. Samples should be taken leading to the preparation of an assay and a geological plan on the scale 1:2000. Drilling should, if possible be carried out in two or three substages and should be undertaken at suitable intervals depending upon whether the deposit is simple , complex ro intricate.

This work should be concluded with complete documentation on all the preliminary work, and result in a rough estimate of the deposit reserves, calculation of raw meal compositions, the usual cement technological investigations and tests and rough suggestions for exploitation of the raw materials. The entire exploration programme in this phase along with the report preparation should be complete within a reasonable time so that an application for mining lease for the most prospective block may be made at this stage.

Phase III: Detailed Exploration

It shall refer to the final phase of exploration that would yield the required quantities of economically minable measured reserve.. This stage will involve mapping in 1:2000 to 1:1000 scale, drilling at close spaced intervals following a grid pattern, the intervals depending upon the type of the deposit. Representative samples should be collected for technological tests and also for tests of the corrective materials.

Exploratory mining should be undertaken, if and when required. This phase should culminate in the preparation of a detailed project report and should enable the project authorities to start mining in a suitable portion of the most prospective block.

Exploratory Mining - It shall refer to the operation that commences after opening up of the deposit in order to additionally ascertain other geological and economic variants in specific parts, sections or portions of a deposit, which are to be brought under immediate mining, with a view to offering assistance in mine layout and grade control.

The prospecting and exploration programme shall consist of the following working procedure:

(a) Surveying
(b) Geological mapping
(c) Trenching
(d) Pit sinking
(e) Drilling
(f) Preparation of plans and sections based on data (a) to (d)
(g) Exploratory mining
(h) Sampling and analysis
(i) Preparation of grade control maps, mine layout plans and sections.

Depending on existing information, some items can be partly or totally left out. Occasionally it may be necessary to carry out part of the tasks. The working procedure must be flexible so that it can always be adapted to changing conditions. Therefore, it is recommended to draw up a summary after each sub-project in order to take it into account when planning and carrying out the next steps in the working procedure.

If required, an exploration stage may be terminated before it is finished as it proves to be fruitful. The excavation and drilling operations shall be carried out, as far as possible, in specific grid patterns. Among the available methods in exploration drilling, three are by far the most popular: diamond core drilling, rotary drilling and percussion drilling. The pattern as well as the quantum and interval of excavation and drilling shall depend on the type of deposit being explored and category of reserve being estimated. It was previously indicated that drilling can be carried out in an area in the first stage of exploration as a reconnaissance drilling or this can be carried out as the direct test of favoruable geologic interpretation or strong geochemical or geophysical anomaly. In the direct tests, a pattern for additional holes develops around the first few drill holes.

The pattern is likely to be simple at first. A certain orientation fits the geologic control or the trend of the anomaly,, and an orebody of a certain size fits the exploration model. A common practice is to drill at a spacing that will allow two neighboring holes to penetrate the minimum-size ore zone. At his stage the pattern is flexible and drill sites are as often coccupied on a basis of accessibiity as they are on a basis of a uniform spacing. New trends and new models may develop as the holes are drilled, and the pattern is adjusted until a satisfactory coverage seems to have been made. This step-by-step approach is generally completed with the first dozen or so holes in a garget area.

The preliminary pattern is abandoned in some projects before it serves its purpose. Some of the early holes may be so exciting that nearby offset holes are drilled immediately and boundaries of the target area are left open for later investigation or for the ultimate insult of having someone who has been attracted by all the activity find a better deposit.

In a well-planned and adequately financed program, drilling on a more systematic grid pattern comes next. A tight grid pattern in the area of greatest interest and a compatible but more widely spaced grid of drill holes in the remainder of the target area will afford adequate coverage without wasting money in needless drilling. Earlier drill holes and existing mine workings are incorporated into the new pattern insofar as possible, but the new grid is otherwise quite specific in that the locations are to be occupied as closely as a reasonable cost for site preparation will permit. Network techniques based on PERT and CPM methods can be used for systematic grid pattern. The main objective of exploration is to find raw material bodies at reasonable cost. Resources, even, "conditional reserves" will not do, as the established cement plant cannot mine probabilities. A trifling discovery will not do because it will not be worth the effort. The economic environment has a lot to do with the size and kind of target sought, and this in turn influences the exploration procedure. If exploration is being done in a remote part of the country to serve the cement industry for at least 40 years accordingly the "raw material deposit" has to contain several million tons of high grade material to be blended with other several million tons of low grade with reasonable chemical analysis to bring the final raw mix "Kiln meal" to the acceptable chemical analysis to satisfy the Standard Specifications. This can be done through raw mix designs.

SAMPLING

Definition - Sampling shall refer to the process of extracting small portion of limestone and associated rocks in the unprocessed state from a deposit such that the physico-chemical properties of the portion shall be representative of the whole.

The "representative" sampling is a chapter by itself and should only be carried out by experienced people. Unprofessional sampling is not only worthless, but may also give a totally wrong impression of the deposit.

Here, we would stress the necessity of the most complete core recovery possible in connection with drilling, which should be no problem with hard and compact rock despite small drill bit diameters (36, 46, 56 mm). With soft, brittle or fine rocks the difficulties increase. There are many methods for achieving a satisfactory core recovery. They are expensive, but the investment pays in the end.

The drilling cores are the most expensive evidence of the exploration work and ought to be treated properly. Drilling cores should be split lengthwise. One quarter (or halves) reserved for technical-physical experiments, half (or quarter) will be stored in a covered room as geological petrographical sample. The last-mentioned half can after some time be sceletised, i.e. that only about 5 cm of each characteristic petrographical, chemical unit from each drill hole is kept.

Location of Samples - Depending upon the phase of exploration, samples shall be drawn from:

a) Outcrops/Natural sections,
b) Pits sunk,
c) Trenches excavated,
d) Boreholes drilled, and
e) Exploratory mine workings.

Phase I of Exploration Programme shall primarily involve outcrop sampling from already existing pits, excavations and old mine workings.

Phase II shall require, in addition, sampling of test pits, trenches and boreholes.

Phase III shall require the sampling of additional boreholes, test pits, trenches and exploratory mine workings undertaken during this stage of work.

Types of Sampling - Depending upon the type of deposit, the specific face being sampled and the ultimate aim of sampling, the nature and mode of sampling should be as follows:

Stage of Exploration	Type of Sampling Recommended
I Reconnaissance Prospecting	a) Grab sampling b) Chip or point sampling c) Strip sampling d) Lump sampling e) Groove sampling
II Detailed Prospecting	a) Channel sampling b) Drillcore/sludge sampling
III Detailed Exploration	a) Drillcore/sludge sampling b) Bulk sampling
IV Exploratory Mining	a) Channel sampling b) Blast hole drill sampling

Sampling Interval

In the initial stage of exploration (Phase I) when the effective thickness of limestone bed is not known, sampling should be a detailed one. The thickness of beds, bands, intercalations showing variation in their lithological composition and structural disposition should be sampled individually at intervals ranging from 0.5 to 1 m. Surface sampling at this stage should be done for every 10 m length.

In the subsequent phase of exploration, the minimum thickness of a bed that may be considered as the sample interval, should be decided on the basis of the fact that this interval would be implementable during actual mining. As an illustrative guideline, the following figures are furnised as sampling intervals in variously dipping limestone beds, assuming that the deposits shall be mined into bench heights of 10 m:

Dip	Interval (in m)
10^o	1.5 to 2.0
10^o to 45^o	2.0 to 3.5
45^o	4.5 to 5.0

With large thickness of lithologically homogeneous beds, the borehole samples should be drawn at intervals of not more than half the planned or customary bench height, that is, not more than 5 m.

The top most bench should have more number of samples, since, in general, it shows more of clay and other intercalations. The above recommendations will need modification in case of deposits showing thick intercalations or bands of clay or shale or irregular intrusion of other rocks.

The length of sectional channel samples should have a relation with their borehole samples as expressed by the following equation:

$$l_c = l_b \cos + \frac{\sin}{\tan}$$

where

l_c = length of sample along a channel,

l_b = length of sample along boreholes,

= inclination of the borehole, and

= dip of the bed.

When the sectional or individual samples drawn at close intervals shall have to be combined into composite samples, the mixing shall be so done as to make the composite samples represent a bench height (say 10 m).

Size, Quantity and Reduction of Samples

The chip, grab or channel samples for chemical analysis may vary from 2 x 2 x 2 cm to 10 x 10 x 20 cm in size and 5 to 10 kg in quantity.

Lump samples intended for mineralogical and physico-mechanical tests should preferably be of dimensions varying from 20 x 20 x 20 cm to 30 x 30 x 30 cm or 0.5 to 1 m long cores, weighing 20 to 50 kg.

The bulk sample(s) for technological tests, "in case of investigations carried out for new cement plants", should be representative of the deposit in case of very uniform and homogeneous deposits with very little variation from bench to bench. In case of deposits showing considerable variation in quality, the bulk sample(s) should not only be representative of the various parts of the deposit, but it should also represent the average material to be mined for the plant. Hence, a bulk sample should be artificially prepared by mixing stones from different parts of the deposits in such a proportion that it shall simulate or bear the closest resemblance to the actual run of the quarry deposit This operation should be the joint responsibility of the mining geologist, mining engineer, mineral beneficiation engineer and the process engineer involved in raw material winning, its processing and utilization. The weight of the bulk sample meant for semi-pilot plant or pilot plant test, shall depend upon the type of technological test, quality of the deposit and the demand of the testing organization. Hence, the exact quantity should be decided upon, in each specific case, in consultation with the testing agency. However, as a general guideline, an amount between 2.5 to 4 tonnes should be sufficient for each run of the test; the number of such runs required should be decided in consultation with the testing agency.

The reduction of all samples other than the bulk samples shall be carried out by sequential crushing, grinding, mixing, screening and cone and quartering. Care should be taken so that the other half of the sample in each stage is retained in every case for reference in future and that the final quarter at each stage of reduction is entirely passed through sieve.

For different technological tests and analyses the minimum quantity of bulk samples required to be tested shall depend on the diameter of the largest particle and the degree of heterogeneity.

Types of sampling (outcrops, pitsinks, trenches, boreholes, exploratory mine-workings, etc.) will depend upon the type of deposit and the ultimate aim of sampling.

Desirable Physical, Chemical and Mineralogical Characteristics:

Some of the desirable physical, chemical and mineralogical properties of cement grade limestone are:

i) The average grain size of calcite in cement grade limestone should preferably be below 0.25 mm, since the grain size has a relation with the burnability of limestone;

ii) The presence of coarse grains of quartz or silicious veins (chert) is undesirable as it may affect the grindability and burnability of limestone;

iii) Chloride content should not exceed 0.05% as it would otherwise cause corrosion and other process difficulties, especially in dry process cement manufacture;

iv) The presence of sulphur, particularly in sulphate state, is undesirable as the decomposition of the sulphate phase is difficult;

v) Limestone should have low natural moisture content;

vi) Limestone should have low compressive strength, preferably below 1000 kg/cm^3.

Technical assessment of limestone consists of:

- Chemical analysis;
- Mineralogical and petrographic analysis; and
- Physico-mechanical tests.

All individual samples collected in the field shall be analysed for one of the following: CaO, MgO and insoluble residues in HCl.

Composite samples shall be prepared from individual samples characterizing the bench height and shall be analysed for SiO_2, Al_2O_3, CaO, MgO, SO_3 and LOI to help in raw mix calculaiton. If the total of the above seven components in the combined samples of carbonate rocks does not exceed 98.5% P_2O_5 and Na_2O + K_2O (R_2O_3) shall be additionally determined. In special cases, where either the geological conditions of the deposits or the technological requirements demand FeO, Mn_2O_3 and C shall also be determined.

Chemical analysis - The complete chemical analysis of cement grade limestone shall refer to the determination of SiO_2, Al_2O_3, Fe_2O_3, FeO, Mn_2O_3, MgO, CaO, Na_2O, K_2O, P_2O_5, SO_3, Cl and LOI. The number of composite samples to be analysed for complete chemical analysis in each phase of exploration should be decided separately in each individual case and according to the type of reserve. 10% of the sample chemically analyzed should be subjected to repeat analysis under secret coding with double HF treatment method to be adopted for some of them. The difference between the two results should be preferably be within the permissible limit as indicated in the following table:

PERMISSIBLE DIFFERENCES IN CHEMICAL ANALYSIS OF COMPONENTS

RAW MATERIAL	PERMISSIBLE DIFFERENCE IN WEIGHT, PERCENT						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI
Pure limestone	0.20	0.10	0.10	0.50	0.20	0.04	0.50
Impure limestone	0.50	0.30	0.15	0.40	0.20	0.04	0.50

Mineralogical and petrographic analysis - This constitutes an important part of technological assessment during all the phases of exploration and may include:

(i) Identification and quantitative estimation of all minerals present, particularly Mg-, S-, P-bearing phases (minerals) and silicious materials.

(ii) Grain size determination of calcite and quartz crystals in this sections with the help of micrometer ocular.

(iii) Texture and microstructural features as evident in hand specimens and these sections. It is also adviseable to conduct micro-chemical tests to distinguish between calcite and do`.mite in the rock, their texture and interrelation.

(iv) Complete mineralogical identification of the insoluble residue in liquid immersion preparation, and possible X-ray diffractometry, infrared spectroscopy, etc.

Physico-mechanical tests - These will determine the following:

- Colour and freacture of limestone;
- Apparent density
- Bulk weight
- Porosity of limestone
- Natural moisture content
- Looseness factor
- Hardness of limestone
- Strength of limestone
- Crushability of limestone, etc.

Maps, samples and drill core will provide feedback and accordingly they can call for revision or radical change in the programme. Few exploration programme design models go further.

Follow-up work amounts to repeated examinations, each ending with a "continue or abandon" decision and based maps, graphs, photographs, cross sections. The degree of generalization (fact versus interpretation) must be taken in consideration.

Estimation of Reserves:

It is worthy to state that so far it has not been possible to establish one single world-wide applicable reserve classification system and we feel that cement industry would profit from a system, based on geostatistics.

The following methods shall be used for estimation of limestone deposits:

- Geological section or cross-section
- Geological or mining block
- Average factor and area
- Polygon, triangle or rectangle
- Contour/isoline/isopach/isochore

A combination of the above methods is also feasible depending upon their applicability.

It is clear that a low grade limestone deposit with high contents of harmful chemical or physical components as well as deposits with complex or intricate geology require the determination of smaller exploration limits "blocks" at a better confidence level than easy, high grade occurrence.

Reserve Estimation in Different Phases

In the Reconnaissance Prospecting Phase the overall minable reserve of the deposit or property may be expressed by the formula:

$$Q = Vd = Smd \qquad \text{...(10)}$$

where

Q = the reserve in tonnes,

V = the volume of the deposit, in m^3,

d = the average bulk weight of the mineral, in tonnes per m^3,

S = the projeciton area of the deposit or part of it within the boundary of the area for reserve calculation, and

m = the average thickness of the deposit along the line normal to the projection plane.

During detailed prospecting, and exploration and proving stages, reserves shall be calculated with appropriate consideration of the utility factor. Here the actual minable reserve shall be calculated and expressed by the formula:

$$Q_m = Q_1 - (Q_2 + Q_3) \qquad \text{...(11)}$$

where

Q_m = actual minable reserve

Q_1 = total reserve in the entire property,

Q_2 = reserve which is not minable due to serveral reasons, and

Q_3 = the quantity of voids and bands of gangue rocks in the limestone.

Some Basic Parameters for Reserve Estimation

During detailed prospecting, reserves shall be calculated according to horizons or customary bench levels in discrete mining blocks and sections, and shall be shown along with the computed grades for each of these blocks or sections in each of the horizons or benches.

The reserves shall be grouped under different intervals of limestone to overburden ration, or limestone to waste ratio, which will give the idea of economic limitations of such calculated reserves at the actual exploration stage. The reserve shall take into account the recovery factors and presence of larger voids and cavities, if they are common in the deposit. If a part of the reserve is under the water table, its minability should be determined with respect to the cost and availability of regular pumping arrangements. Calculations of reserves shall take into consideration the mine laws, rules and regulations, the working limits from the lease boundary, loss of available reserves due to installation of public structures, such as roads, railways, power lines, etc. and safety distance from habitations. The loss of reserve in quarry benching shall also be taken into account in calculating the measured reserve.

The depth of exploration and reserve estimation should generally be limited to 30 to 40 m from the surface up to a certain level depending on the pysiographic and other factors.

Recording and Reporting of Data

The recording data shall include the following:

a) Maintainting the field diary by the exploration geologists,
b) Maintaining the record of sampling during the period of exploration and
c) Documentation of analysis results and deposit characteristics.

The field diary of the exploration geologists should contain exhaustive details of field observations with on-the-spot sketches of natural sections, lithological variations, joint patterns and all other geological and structural features of importance.

The record of sampling at all phases of exploration should be accurately maintained in proper forms and tables.

For documenting the results of analysis, an appropriate index and system may be followed.

Exploration data shall be presented in two types of reports:

a) Interim Assessment Report; and
b) Techno-economic Report.

Interim assessment report shall pertain to phases I and II. It shall be necessary for planning the subsequent phase of exploration programme as well as for taking interim actions on prospecting licence or mining lease.

Techno-economic report shall be submitted separately after completion of Phase III.

The techno-economic report shall be the basic document for assessing the feasibility of quarrying in a given property and setting up of a plant based on that quarry.

Each report shall contain: a) Synopsis; b) Main body of the report covering the background information and exploration details; c) Concluding and recommendation sections; and d) Appendices containing sample records, borehole logs, analytical or test results, details of reserve computation maps, sections, plates, photographs, etc.

Some of the information may, however, remain more or less common or unchanged for the same prospect in all the successive reports during various stages, but these should not be excluded altogether so that all the reports remain comprehensive at all stages.

The common outline for all the reports should be:

a) Introduction - location and communication, climate, vegetation, topography, drainage pattern, etc; summary of previous work objective and scope of present investigation, period of investigation, etc; and acknowledgement and other points.

b) Geological and structural features - Stratigraphy, lithology, geomorphology and structure to be described under "Regional geology" and "Local geology".

c) Details of exploration - Geological, Geophysical if applied, Surface mapping, Exploratory excavations, Drilling, Sampling and if applied (for study of any possible underground extension of the deposit) Summary table of quantum of exploration.

d) Results of analysis of samples - Chemical, Mineralogical and petrographical and Physico-mechanical.

e) Discussion of field observations and results of analysis should be aimed at (1) Type, extent and outline of deposit; (2) Geologically founded assumptions or explored evidence regarding the depth of occurrences; (3) Lithological composition; (4) Quality of limestone and its degree of consistency; (5) Mining indices like thickness of overburden, overburden to limestone ratio, etc; (6) Geohydrological conditions; (7) Transport facilities; and (8) Techno-economic factors like availability of fuel, power, water, land for plant site, etc.

f) Reserve and grade - type of reserves and its reliability.

g) Conclusions and recommendations - Outline of the deposit; Broad workability of the deposit in the context of reserve, grade, and other parameters of interest; Scheme and programme of further work indicating the quantum and other specific details; Disposal of waste/overburden/tailing, etc.

The conclusions and recommendations part of the techno-economic reports after phase III should, however, be more specific with regard to method of mining, expected recovery of limestone, flowsheet for beneficiation, approximate capital investment in mine development and expected cost of mining.

Depending upon the phase of exploration, type and number of diagrams to be appended to a report shall very. However, as a guideline, the following list may be consulted in deciding the contents of an appending:

a) Geological map on large scale showing all possible and available details of geology and exploration work. In case the data are too numerous and diverse to be presented in a single map, separate maps showing geological features, boreholes, pits, trenches, sample points, roof and floor contour, etc. may be prepared.

b) Geological cross-sections on the basis of available data, interpretations and assumptions.

c) Assay maps or plans for CaO, MgO; isopach bar charts and histograms showing quality distribution and variation.

d) Isometric block diagram of the deposits.

e) Detailed log of boreholes and excavations.

f) Sample records.

g) Analytical or test data cards.

h) Slice plans, and other reserve estimation plans with data considered and methods applied.

i) Photographs and plates of relevance.

j) Recommended equipment to be applied in mining the deposits.

k) Forecast of consumable materials, spare parts based on experience and the corresponding expected costs.

l) Develop the best working design for quarrying and to locate the quarry in an optimum area, and ensure the most efficient fragmentation of rocks.

Exploitation Concepts

After fulfilling all the requirements regarding exploration and investigating the raw materials, planning for quarrying has to be explained in detail based on some specific principles.

Quarry planning is considered as one main factor in assuring that the quality of raw material produced is complying and responding with the requirements of product and manufacturing process. Quarry planning comprises all activities procedures and measures designed to ensure a continuous and economic supply of raw materials. The following scheme shows the situation of quarry planning in respect to the quality assurance strategy.

		Economy
		Product requirements
Quarry site selection	Quarry planning	Manufacturing process
		related requirements

Selection of Quarry Site

Based on investigations, explorations and the raw mix designs for the different qualities of the raw material available, a specific plan for exploiting the quarry and proportioning the different grades has to be considered closely to the process of selecting and evaluating potential quarry site. Based on the raw mix design and the different percentages of proportioning quarry sites are selected first followed by quarry exploitation scheme. However, in certain cases it is possible that quarry planning, according to its significance within the quality assurance scheme, entails a reconsideration of the quarry sites. There are some specific factors affecting the selection of quarry sites, e.g.

- Geological criteria: Stratigraphy, Lithology - Tectonics - Overburden
- Topography, Physiography
- Raw material characteristics: Humidity - Homogeneity - Chemical and mineralogical characteristics - Physical characteristics
- Raw Mix Designs: Characteristic of the different types of available raw material, proportioning aspects

- Handling characteristics: Fragmentation - Stickiness - Dumping - Transport, haulage
- Climatic conditions
- Operating parameters: Drainage, groundwater - Safety measures
- Accessibility, infrastructure
- Market considerations: Product quality - Product types - Proximity to market area (i.e. proximity to cement works)
- Ecology, environmental impact
  Noise, dust, vibration, pollution - Rehabilitation

Practically, the above-mentioned criteria are not of the same importance. Their significance depends on the actual local conditions.

Quarrying Techniques

Quarrying techniques are either:

a) Strategic "selective - non-selective, overburden, etc."
b) Operational "quarrying system bench definition, face height, width, length - fragmentation - method of extraction - blasting - ripping - environmental impact.
c) Engineering "Selection of quarry equipment - access haulage, drainage, supply of power, etc. - buildings