CEMENT RESEARCH INSTITUTE OF INDIA

CRI TECHNOLOGY DIGEST

GEOSTATISTICAL METHODS IN LIMESTONE EXPLORATION

November 1982

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PART I

INTRODUCTION

Application of statistical methods in geological exploration is not a new idea. Geostatistical evaluation of exploration data has been adopted, as a general practice for many base metals and strategic mineral exploration activities (copper, lead, zinc, atomic minerals), where statistical approaches have been found to provide a key to the understanding of mode of occurrence, distribution, quality and quantity variations, etc, of vein-type deposits, which are usually tortuous in their mode of occurrence, trecherous in their presence and unpredictable in quality and quantity.

Bedded deposits, including cement grade limestone, so far have not been covered by statistical appraisal, as these are usually continuous in occurrence and uniform in composition. However, during the last few years, several developments in cement manufacture have created a need for thorough appraisal of the limestone exploration data. These are: (a) Many old plants are left with depleted reserves of good quality limestone and have to use marginal or heterogeneous deposits in increasing amount. (b) Most new plants are large sized (3000 tpd and above) and are based on dry process suspension preheater systems. Such plants need very uniform quality of the raw meal feed and cannot tolerate variations in contents of certain minor constituents in the raw materials beyond specific limits. (c) Good quality limestone deposits are becoming depleted and available in lesser quantities to the cement industry. Both new and future plants have to rely more on marginal or inhomogeneous deposits. Statistical appraisal of exploration data becomes necessary to understand the variability to evolve a rational utilization pattern for the purpose of maintaining a more or less uniform quality of limestone fed to the plant.

This Technology Digest deals with the scope of use of geostatistical methods in exploration and technological assessment of limestone for cement manufacture.

SCOPE OF APPLICATION

Geostatistical approaches in limestone exploration for cement has already been adopted in Europe, primarily for the aforesaid reasons; but the need having been more accentuated by several other factors eg, (a) stringent quality specifications of cement which need corresponding stringent quality control on raw materials; (b) lesser availability of good quality limestones on account of strict and statutary pollution and environmental control measures being increasingly implemented for non-renewable natural resources. A few precursor applications of geostatistics in limestone exploration are provided from Hungary, USSR and West Germany. A comparative study in Hungary between the conventional and geostatistical methods in reserve calculation made in 1976 revealed that although both give equally reliable results for blockwise quality and tonnage, the geostatistical method is a better choice because of its ability to predict estimation variance and capability to pinpoint areas needing additional exploration to attain necessary confidence limit. The usefulness of geostatistical methods has been highlighted in another study in West Germany, where the number of samples required to determine a parameter (say CaO content) with given accuracy (say $\pm$ 1% variation) has been calculated with the help of a formula on required mean value of the parent population.

In India the need for geostatistical approaches in limestone exploration was first stressed in the "Guide norms for prospecting, exploration, reserve estimation and technological assessment of cement grade limestone deposits", published by CRI in 1975. The publication has since been revised in 1981 as "Norms for proving limestone deposits for cement manufacture" (SP-9-81). It devotes one chapter exclusively to the topic dealing with principles of geostatistical methods of calculations and their scope of application under various circumstances, illustrated by a number of case studies on actual application. The feedback on implementation of norms in limestone exploration monitored by CRI in 1975-76 through circulation of a questionnaire to all cement plants and State Geology Departments involved in limestone exploration, revealed that only a few are using the statistical methods, mostly in preliminary calculations, such as, in correlating core and sludge analysis, reserve calculation (errors in estimation), standard deviation of average grade, etc. Although a large number of organizations conveyed their willingness to use geostatistical methods in exploration activities, they are unable to use such

methods on account of several reasons such as:

a) inadequate data, the prospecting being done by other agencies,

b) the deposits being simple and uniform and not apparently needing statistical evaluation, and

c) lack of personnel trained in the subject.

CRI'S ROLE IN PROMOTING GEOSTATISTICAL EVALUATION OF LIMESTONE DEPOSITS

To fill in the aforesaid gap, CRI has evolved methodologies for more reliable evaluation of quality and quantity data generated from exploration of any type of limestone deposit and has also worked out schemes for mine planning for inhomogeneous limestone deposits towards optimized quarrying for uniform and quality controlled limestone feed to plants. Studies completed on techno-feasibility of preblending limestone took into account the difficulties in using varying qualities of limestone from a quarry and suggested methods of quality control in quarrying. Depending upon the complexity of the deposit, ie, its quality-wise variations, the required quality of stone may be obtained through rational mine planning, rational mine planning along with blending at crusher or, for erratic variations, by bed blending. The primary prerequisite for choice of any of above quality control measures will depend upon thorough appraisal of quality variations. On the basis of studies completed on a number of deposits, a formula has been evolved:

$$C = \frac{V}{F \times M}$$

where C is complexity of the deposit,

V is variability (in quality, thickness etc),

F is recovery factor and

M is minability.

It has been calculated that for any deposit,

(a) values of C between 0-49 indicate need of rational mine planning;

(b) values of C between 50 and 100 indicate quality control through rational mine planning and blending at crusher; and

(c) values of C above 100 indicate need for bed-blending.

The results obtained for a few deposits studied for this purpose are:

Deposit	*Complexity*	*Recommended Mode of Homogenization as Indicated Above*
Deposit A	Complex to Intericate	(b) and (c)
Deposit B	Simple to Complex	(a) and (b)
Deposit C	Simple to Complex	(b)
Deposit D	Simple to Complex	(a) and (b)
Deposit E	Simple	(a)

From detailed geostatistical appraisal of a large number of limestone deposits "Mathematical models for exploitation and technological assessment of limestone", have been evolved. In evolving such a model for any deposit, the parameters that need be studied are:

a) Complexity of a deposit to decide upon quantum of exploration.
b) Optimum level of sampling depending upon the deposit complexity.
c) Prediction of one value with respect to another at unexplored points/areas.
d) Representativeness of boreholes to estimate their adequacy for a deposit.
e) Assay values distribution pattern to evolve a rational mine plan for quality control and conservation.

The geostatistical analytical techniques which have been found suitable for such studies are:

a) *Determination of complexity of a deposit*—Variance, covariance etc, determined with respect to thickness, over-burden, chemical variability etc.
b) *Choice of optimum sampling pattern*—Study of variation associated with various extent of sampling by *analysis of variance* (*ANOVA*) gives estimate of component of variance at various sampling levels.
c) *Prediction of one parameter with respect to another*—
   i) Interrelationship established by linear or multiple correlation coefficient,
   ii) Regression analysis for interpolating or extrapolating values.

d) *Representativeness/adequacy of boreholes*—Different techniques of interpolation like moving average, Kreiging Methods.

e) *Determination of assay value distribution pattern*—Computerized trend surface analysis of assay values in three dimensions.

Further details on methods of a geostatistical calculation of above parameters will follow in Part II of the CRI Technology Digest on the subject.

CRI EXPERTISE

Keeping in view the trends in mining practices and the need for trained personnel in order to gainfully apply the geostatistical methods in limestone exploration, CRI has been conducting contact programmes and training courses for the benefit of Indian Cement Industry. More than 100 technical personnel have been trained in geostatistical methods through a number of training courses. The Institute offers its assistance to such organizations as may like to incorporate these methods in their exploration activities.

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