Methods of Mining Geology and Estimation of Ore Reserves

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By

P.S.N. Murthy

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Dedication

This book is dedicated
in memory
of my mother Late Annapurna
and
father late Surya Subrahmanyam

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Part II: Classic Methods of Assessment of Ore Reserves and their Classification

Part III: Basic Mathematics and Statistics

Part V: Case Studies by Classical Methods, Linear Geostatistics and Non-linear Geostatistics

Part VI: Production Scheduling, Quality Control, Practical Problems in the Application of Geostatistics and Computer Programmes

FOREWORD

There are books in the public domain that deal with different elements of mining geology and those that deal exclusively with variants of techniques for estimation of ore reserves. Both fields have their unique specializations but are incomplete in isolation. Mining Geology and Estimation of ore reserves are highly interdependent fields. The present book envelopes essentials of both the fields in a seamless manner.

What makes Mining Geology complete or comprehensive? Ore genesis and structural geology constitute the initial concepts. These have to be followed by extensive field surveys and field geology activities. Concurrently or subsequently, ore proving operations like drilling, pitting, trenching and other mine opening activities follow. Based on all the data originating from field measurements and exploration activities, multiple projection techniques are used to define the geometry of ore bodies finally leading to estimation of ore resources/reserves. The estimations of ore reserves are made using multiple classic methods. In the sixties, statistical and subsequently geostatistical techniques were developed for estimation of ore reserves which allowed estimation to be linked to likely estimation errors. Geostatistical methods also allowed optimization of estimator with minimization of estimation errors. Further developments in Geostatistics have led to innovative techniques and applications.

Geostatistical applications in ore reserves estimation need a reasonable base in mathematics and mathematical statistics. Geologists, in general, either do not have adequate exposure to required concepts of mathematics and mathematical statistics or the impact of acquired exposure generally diminishes, as the field studies get prioritized in the initial phase of the profession. It is therefore prudent that any effort in presenting a comprehensive text on such a subject brings out a refresher in these fields as in this book obviating the need to refer to separate books on these topics.

It would thus emerge that a comprehensive text on Mining Geology and Reserves Estimation will coverage of multiple sections as discussed above on a standalone basis. It is in this context that the book presents an excellent attempt in covering all essential sections that are needed for a successful mining geology professional. Inclusion of about 700 extensive illustrative

diagrams lends greater clarity of the concepts presented. The entire coverage in the book may be summarized under the following principal components:

(a) **Ore Genesis** covered under a chapter on Mineral Deposits
(b) **Surveying, Field Geology and Exploration** covered under chapters like surveying methods, geological mapping, strike/dip measurements, drilling and sampling and density and units
(c) **Elements Relating to Conventional Ore Reserves Estimation** covered under chapters like types of projections, methods of contouring, area calculations, cross sections and bench plans, geometric methods and distance weighing methods for ore reserves estimation
(d) **Elements of Mathematics** covered under chapters like properties of triangle, permutations/ combinations and binomial theorem, matrix algebra, determinants and integral calculus
(e) **Mathematical Statistics** covered under chapters like frequency distribution, central tendencies, ser theory and probability, curve fitting and correlation
(f) **Geostatistics and its Applications Including Case Studies** covered under chapters like theory of regionalized variables, concept of variogram, auxiliary functions and charts, variance of estimation, variance of dispersion, regularization, theory of kriging, theory of co- kriging, log normal kriging, geological and statistical studies, kriging and co- kriging studies, optimum drilling grid, global recoverable reserves, practical problems in practice of Geostatistics. Apart from the theoretical concepts, typical examples, solved problems, problems with answers have also been presented to help grasp the concepts with clarity
(g) **Evolving Concepts in Geostatistics** covered under chapters like non- linear Geostatistics, disjunctive kriging, recoverable resource estimation by indicator kriging and conditional simulation.

The estimation of mineral resources/ reserves concludes with their classification for the purpose of decision making for their eventual developments. The section on classification of mineral reserves reviewing various international codes is an appropriate inclusion. Finally, extending the scope beyond resource estimation, the geological functions in operating mines are welcome additions covered under the chapters like production planning and quality control in mines and management and quality control at stockpiles.

A review of the various components contained in the book leads to a logical conclusion that each chapter is adequately covered to meet the intended objective. The book begins with the theoretical background relating to mining geology and ends with production planning and quality control in mines and at stockpiles with all associated intermediate elements and concepts required to meet the ultimate objective of understanding an ore deposit and contributing to the mine development plan effectively. The integrated coverage of all the relevant sections in the book presents a comprehensive and uniquely designed knowledge base on a single platform that should be of interest to all the professionals in the field of Mining Geology including students and teaching faculty. I am of the opinion that this book book would serve both as a text book and as a reference book.

Dr TRP Singh
Hon.Advisor, Ministry of Earth Sciences
Govt of India

PREFACE BY THE AUTHOR

Since I had an opportunity to study at some of the worlds' leading Institutes namely Montanistische Hochschule, Leoben (Austria) and Centre De Geostatistique, Ecole Des Mines de Paris, Fontainebleau (France) and work in National Mineral Development Corporation, India, some of my colleagues and friends advised me to consolidate my professional experience as a book on "Methods of Exploration and Ore Reserves estimation".

It is hereby clarified that is not an exclusive book on "Geostatistics". Calculation of ore reserves a part of the book and Geostatistical ore reserves calculation is only a part of the methods of ore reserves calculation.

This book comprises six parts. In each part there are many chapters.

The first part deals with filed geology and measurements and has seven chapters. The second part deals with Classic methods of assessment of ore reserves and their classification. The third part which has ten chapters deals with basic mathematics and statistics required to understand the book. The fourth part has ten chapters and deals with theory and exercises in linear geologists. The exercises are about hundred in number. The fifth part has ten chapters that deal with practical case studies by classical methods, and linear and nonlinear Geostatistical studies. The sixth part has three chapters, dealing with miscellaneous aspects like Production scheduling, Quality Control and associated Elements

Now a days some students have an easy tendency for readymade solutions on computers. In other words, without a computer they cannot make any cross sections and calculate the ore reserves. But the ground truth is Mining

geologists should have the basic knowledge of the mode of occurrence and sub-surface behaviour of the any mineral deposit.

Further supplementing integrals are structural geology and principles of mining geology like mapping including underground. A mining geologist will be called upon to prepare topographic profiles, cross sections, longitudinal sections, and bench plans etc.

Reserves can be estimated both by conventional methods and geostatistical methods.

Errors associated the concept of extension in Geometrical Methods are critically evaluated. Among the conventional methods, Inverse distance square method is used more frequently by many mining companies. But in this context, there are specifics associated with the method not dealt with by others in their books. These have been addressed along with solutions.

As geologists have to understand different classifications of mineral deposits including international, there is an imperative to fully defines resources and reserves. These aspects find detailed discussion in a lucid and simple style. `

The present book as such takes into consideration only delimited or defined deposits and does not take into consideration, the earlier stages like reconnaissance, prospecting by different geological, geophysical and geochemical methods.

Because of technical advancement, descriptive knowledge does not find a place, at least now a days. Even to estimate the ores by classical methods, some knowledge of the geometry is required. A chapter on the mathematical aspects is included.

An Exploration Geologist either in a small mining company or a big mining company should have good grounding in the classical methods. He must be equipped with multifarious skills like, mapping, surveying, drilling, sampling, etc. Further detailed understand of contouring, different types of projections, preparation of profiles, cross sections, bench plans, grade estimation etc. These details are elaborated in part 1 and 2.

Geology students of India particular have different levels of knowledge in the mathematics. To learn Geostatistics, knowledge of Permutations, combinations, Binomial theorem, Matrix algebra, Determinants, Integral calculus including multiple integration, Probability theory, set theory, conditional probability is required. Instead of necessity of searching for

many books, all the required mathematics is presented, at one place, in the third part.

The fourth part deals with the theory of Geostatistics. It deals with the theory of regionalized variables, concept of variogram, co-variance, variance of estimation, variance of dispersion, regularization, concept of global variance. Examples are presented wherever needed. It presents solved problems. The style will be more like self-explanatory.

The fifth part of the book presents case studies. It presents the results of geological and statistical studies. Before dealing with, case studies on Geostatistics, the status of Geostatistics in India is presented. kriging - cokriging studies, fixation of optimum drilling grid in the case of iron ore deposits with Multivariables. It presents the necessity of Non-linear Geostatistics, case studies Change of support and Global recoverable reserves, Disjunctive Kriging and conditional simulations.

It is proposed to present Executable computer programs in a pouch, with user's manual at appropriate places in the chapters. The computer programs are in respect of calculation of areas by analytical geometry, Auxiliary functions like Chi, F and H, calculation of different types of variances in one dimension and two dimensions, calculation of average grade by inverse distance methods, and by Kriging.

The sixth part has three chapters. Be it a conventional method or geostatistical method there are, limitations. One chapter deals with the practical problems and limitations in the application of Geostatistics. One chapter deals with Mine planning, preparation of Mining schedules, long term and short term mine planning, quality control aspects, exclusively. The last chapter deals with the designing, management of stockpiles and quality control.

It is hoped that this book would benefit the Graduate and post graduate students of Applied Geology, teachers in universities dealing with Economic Geology and applied geology and professionals engaged in Exploration and Mining Activities as this book as it serves both as text book and reference book.

Dr. PSN Murthy
Former General Manager (Investigation Division),
NMDC Ltd, India.
Former Expert (Geology and Geostatistics),
Govt. of Saudi Arabia.
Former General Manager (Exploration),
Essar Steel, India.