
Contents

Introduction: Why Geostatistics?	1
The Requirement for Spatially Related Statistics	1
The Concept of a Spatially Regionalized Variable	4
Subsurface Variables	4
Geological Influences	4
Geological Discontinuities	5
Origins in the Prediction of Gold Grades for Mining	7
Applications in the Geosciences	9
Evolution of an Integrated Approach	9
Integrated Computer Techniques	10
Characterization Quality Concerns	11
Advantages and Disadvantages of Geostatistics	13
Advantages of Geostatistics	13
Disadvantages of Geostatistics	14
Data Types and Structures for 3D Geostatistics	16
Data Types: Variables, Characteristics and 3D Conventions	16
Management of Information Sources	16
Data Types	17
Data Structures	17
Hole Data Structure for Borehole Samples and Observations	21
Hole Geometry	21
Hole Data Associations	22
Map Data Structure for Point, Survey and Map Information	24
Map Geometry	24
Map Data Associations	26
Volume Data Structure for Geological Structures and Stratigraphy	27
Volume Geometry	28
Volume Data Associations	29
Grid Data Structure for a Continuous Measure of a Regionalized Variable	31
3D Grid Geometry	31
3D Grid Data Associations	32

Basic Concepts and Theory of Geostatistics	34
Analysis fo the Spatial Variability of a Regionalized Variable	34
Spatial Variability of a Regionalized Variable	34
Measurement of Spatial Variability	36
Derivation of a Mathematical Model of Spatial Variability	41
Understanding Geostatistical Semi-Variograms	42
Semi-Variogram Models	43
Geostatistical Estimation of a Regionalized Variable	45
Estimating a Regionalized Variable at a Point	45
Sample Selection Criteria for Geostatistical Estimation	47
Estimating a Continuous Measure of a Regionalized Variable	48
Cross-Validation and Other Checks on Geostatistical Estimation	52
Cross-Validation of a Semi-Variogram Model	52
Cross-Checking of the Results of Geostatistical Estimation	53
Common Problems in Geostatistical Estimation	55
Integration of Geology with Geostatistics	57
Analysis of Geological Influences in a Regionalized Variable	57
Analysis of Geological Influences	57
Estimation with Geological Influences	59
3D Interpretation of Geological Structures and Volumes	60
Sectional Interpretation of Geological Volumes	60
3D Interpolation of Geological Volumes	62
Generating Viewplane Sections Through Geological Volumes	63
Considerations for 3D Interpretation	65
Generation of Geological Volumes between Triangulated Surfaces	66
TIN Representation of a Geological Surface	67
Manipulation of TIN Surfaces	69
Derivation of Volumes from TIN Surfaces	70
Geostatistical Estimation with Geological Control	72
Volumetric Intersections of Geological Volumes	72
Geostatistical Estimation with Geological Control	73
Grid Data Structure Considerations	75
Alternative Approaches to Representation of Geology	77
Practical Application of Geostatistics	80
Data Transform for Non-Normal Sample Distributions	80
Non-Normal Sample Distributions	80
Log Transform	81
Indicator Transform	82
Rank Order Transform	83
Normal Scores Transform	84
Practical Application of Data Transforms	84
Underlying Trends and Estimation of Residual Values	86
Semi-Variogram Analysis with a Determinate Trend	86

Estimation with a Determinate Trend	87
Anisotropy and Estimation with Directional Control	88
Analysis of Anisotropic Spatial Variability	88
Estimation with Anisotropic Spatial Variability	89
Volume Estimation of a Regionalized Variable	91
Estimation for a Volume Instead of a Point	91
Geostatistical Uncertainty and Probability	93
The Normal Distribution, Standard Error and Probability	93
Estimation Uncertainty	93
Spatial Variation of Uncertainty	95
Standard Error as a Measure of Estimation Uncertainty	97
Estimation Volumetrics and Uncertainty	97
Geological Estimation and Uncertainty	100
Sampling Control Applications in Geostatistics	102
Sampling Control with Semi-Variogram Analysis	102
Sampling Control with Estimation Uncertainty	103
Indicator Transforms and Probability Estimation	106
Estimation of a Probability Variation	106
Quantitative Approach	106
Qualitative Approach	108
Other Techniques for Estimation of a Regionalized Variable	111
Contour Techniques	111
Conditional Simulation	112
Direct Volume Estimation for Thin Seams	113
Visualization and Spatial Analysis	115
Volumetrics Analysis of a Regionalized Variable	115
Manipulation of the Results of Geostatistical Estimation	119
Volume-Weighted Averaging of Estimated Variations	119
Combining Two or More Estimated Variations	120
Generation of a Net Value Variation	122
Direct Volume Estimation of a Regionalized Variable	124
Geostatistical Approximations	124
Theoretical Basis of Direct Volume Estimation	125
Practical Application of Direct Volume Estimation	126
Advantages of Direct Volume Estimation	127
Practical Data Management for Geostatistics	128
Data Integration Issues	128
Coordinate Issues	128
Geologcial Integration	128
Data Capture Formats	129

Data Verification Techniques	131
Sampling Issues	131
Geological Observation Issues	131
Statistical Techniques	132
Geostatistical Techniques	133
Visualization Techniques	134
Qualification of the Results of Subsurface Characterization	135
Semi-Variogram Analysis	135
Cross-Validation Analysis	135
Estimation Comparisons	136
Estimation Uncertainty	137
Geological Uncertainty	137
Characterization Reporting	139
Practical Geostatistics	140
Worked Example: Grade Characterization of a Zinc Ore Deposit	140
Site Investigation	140
Data Review, Statistics & Semi-Variogram Analysis of Samples	141
Cross-Validation of Semi-Variogram Models	142
Unconfined Geostatistical Estimation of Ore Grades	142
Interpretation of Deposit Ore Types	143
Ore Grade Estimation with Geological Control	143
Spatial Analysis of Ore Grade Variation	144
Worked Example: Environmental Characterization and Assessment of Soil Contamination	145
Site Investigation	146
Data Review, Statistics and Geostatistical Analysis	146
Generation of Soil Geology	147
Probability of Contaminant Variations	147
Spatial Analysis and Volumetrics	148
Sample Optimization and Quality Control	149
Worked Example: Mineral Characterization of a Copper Ore Deposit	150
Site Investigation	151
Data Review, Statistics & Semi-Variogram Analysis of Samples	152
Interpretation of Deposit Geology	153
Ore Grade Estimation with Geological Control	153
Spatial Analysis of Ore Grade Variation	154
Worked Example: Geotechnical Characterization for a Tunnel Project	155
Site Investigation	156
Data Review, Statistics & Semi-Variogram Analysis of Samples	156
Interpretation of Project Geology	157
Probability Estimation of Soil Properties	157
Probability Estimation of Rock Properties	158
Source Data for the Worked Examples	159
Source Data Locations and Contents	159
Credits	161