Contents

Introduction: Why Geostatistics? 1

The Requirement for Spatially Related Statistics 1
The Concept of a Spatially Regionalized Variable 4
Subsurface Variables 4
Geoloical 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 Mathemathical 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