Contents

Introduction		
Part I	Economic Geology, Mineral Exploration, and Mineral Development	
1	Mineral Deposits and Metallogenic Concepts	5
1.1	Composition of the Earth and Types of Mineral	
	Resources	8
1.2	Geologic Cycles and the Formation of Mineral Deposits .	10
1.2.1	Mineral Deposits Associated with Magmatic Processes	11
1.2.2	Mineral Deposits Associated with Sedimentary	
	Processes	14
1.2.3	Mineral Deposits Associated with Metamorphic	
	Processes	16
1.3	Geologic Models of Mineral Deposits	17
2	Exploration Methods	22
2.1	Development Phases of Exploration and Mining	
	Projects	23
2.2	Exploration Strategies, Procedures, and Stages	26
2.2.1	Program Design	26
2.2.2	Reconnaissance Exploration	27
2.2.3	Detailed Follow-up Exploration	27
2.3	Exploration Methods	29
2.3.1	Remote Sensing	30
2.3.2	Aerial Photography	32
2.3.3	Geologic Exploration	34
2.3.4	Geophysical Exploration	34
2.3.4.1	Magnetic Surveys	37
2.3.4.2	Electric Surveys	38
2.3.4.3	Electromagnetic Surveys	40
2.3.4.4	Radiometric Surveys	41
2.3.4.5	Gravimetric Surveys	41
2.3.4.6	Seismic Surveys	43
2.3.4.7	Airborne and Ground Geophysical Surveys	44
2.3.5	Geochemical Exploration	45

2.3.5.1 2.3.5.2 2.3.5.3 2.3.5.4 2.3.5.5 2.3.5.6 2.3.5.7 2.3.5.8	Stream Sediment Geochemical Surveys47Hydrogeochemical Surveys48Soil Geochemical Surveys48Biogeochemical Surveys49Atmospheric and Vapor Geochemical Surveys50Rock Geochemical Surveys51Analytical Methods51Interpretation of Geochemical Surveys53
3	Quantitative Assessment of Mineral Potential
3.1	Accessing the Ore
3.1.1	Trenching and Pitting 58
3.1.2	Drilling
3.1.3	Drill-Hole Geophysics
3.1.4	Underground Exploration 61
3.2	Sampling and Assaying of the Ore
3.2.1	Sampling
3.2.2	Sample Preparation
3.2.3	Chemical Assays
3.3	Ore Reserve Estimation
3.3.1	Geometric Methods of Ore Reserve Estimation 64
3.3.2	Statistical Methods of Ore Reserve Estimation 66
3.3.3	Geostatistical Methods of Ore Reserve Estimation 67
3.3.4	Classification of Reserves and Resources
4	Mining and Mineral Processing
4.1	Mining
4.1.1	Surface Mining
4.1.2	Underground Mining
4.1.3	Solution Mining
4.1.4	Marine Mining
4.1.5	Strategies and Trends in Mining
4.2	Mineral Processing

Part II Mineral Economics

5	The Economic, Institutional, and Legal Framework		
	for Mineral Development	85	
5.1	Mineral Development as an Economic Activity	85	
5.2	Participants in Mineral Development	87	
5.3	Mining Law		

6	Economic Evaluation of Mineral Deposits	. 94
6.1	Goals and Strategies	. 95
6.2	Methods of Investment Analysis	. 96
6.2.1	Cash Flows and the Time Value of Money	
6.2.2	Benefit-Cost Analysis	
6.2.3	Risk Analysis	
6.3	Evaluating Exploration Projects and Mineral Deposits	
6.3.1	Program Design	
6.3.2	Reconnaissance Exploration	
6.3.3	Detailed Exploration and Initial Target Evaluation	
6.3.3.1	Minimum Acceptable Reserves – Tonnage and Grade	
6.3.3.2	Cutoff Grade	
6.3.3.3	Optimal Scale of Operation	113
6.3.3.4	Cash-Flow Analysis	
6.3.3.5	The Prefeasibility Study	117
6.3.4	Detailed Target Evaluation and the Feasibility Study	
6.3.4.1	Legal Factors	
6.3.4.2	Fiscal Regimes	
6.3.4.3	Environmental Regulations	
6.4	Financing	
6.4.1		
6.4.1 6.4.2	Exploration Projects	
0.4.2	Mine Development	. 127
7	Mineral Markets	. 132
7.1	Mineral Markets	
-		. 133
7.1	Market Structures	. 133 . 134
7.1 7.1.1	Market Structures	. 133 . 134 . 135
7.1 7.1.1 7.1.1.1	Market Structures	. 133 . 134 . 135 . 137
7.1 7.1.1 7.1.1.1 7.1.1.2	Market Structures Determination and Alteration of Market Structures The Tin Market The Aluminum Market The Gold Market Market Shares of International Mining and Oil	. 133 . 134 . 135 . 137 . 138
7.1 7.1.1 7.1.1.1 7.1.1.2 7.1.1.3	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Gold MarketMarket Shares of International Mining and OilCompanies	. 133 . 134 . 135 . 137 . 138 . 141
7.1 7.1.1 7.1.1.1 7.1.1.2 7.1.1.3	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Gold MarketMarket Shares of International Mining and OilCompaniesMarket Organizations	. 133 . 134 . 135 . 137 . 138 . 141 . 142
7.1 7.1.1 7.1.1.1 7.1.1.2 7.1.1.3 7.1.2	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Gold MarketMarket Shares of International Mining and OilCompaniesMarket OrganizationsProducer Associations	 . 133 . 134 . 135 . 137 . 138 . 141 . 142 . 144
7.1 7.1.1 7.1.1.1 7.1.1.2 7.1.1.3 7.1.2 7.2 7.2 7.2.1 7.2.1.1	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Gold MarketMarket Shares of International Mining and OilCompaniesMarket OrganizationsProducer AssociationsPetroleum Associations (OPEC, OAPEC)	. 133 . 134 . 135 . 137 . 138 . 141 . 142 . 144 . 145
7.1 7.1.1 7.1.1.1 7.1.1.2 7.1.1.3 7.1.2 7.2 7.2.1	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Gold MarketMarket Shares of International Mining and OilCompaniesMarket OrganizationsProducer AssociationsPetroleum Associations (OPEC, OAPEC)Copper Associations (CIPEC and Others)	 . 133 . 134 . 135 . 137 . 138 . 141 . 142 . 144 . 145 . 150
7.1 7.1.1 7.1.1.1 7.1.1.2 7.1.1.3 7.1.2 7.2 7.2 7.2.1 7.2.1.1	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Gold MarketMarket Shares of International Mining and OilCompaniesMarket OrganizationsProducer AssociationsPetroleum Associations (OPEC, OAPEC)Copper Associations (CIPEC and Others)Bauxite Association (IBA)	 . 133 . 134 . 135 . 137 . 138 . 141 . 142 . 144 . 145 . 150 . 153
7.1 7.1.1 7.1.1.1 7.1.1.2 7.1.1.3 7.1.2 7.2 7.2.1 7.2.1.1 7.2.1.1	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Gold MarketMarket Shares of International Mining and OilCompaniesMarket OrganizationsProducer AssociationsPetroleum Associations (OPEC, OAPEC)Copper Associations (CIPEC and Others)	 . 133 . 134 . 135 . 137 . 138 . 141 . 142 . 144 . 145 . 150 . 153
7.1 7.1.1 7.1.1.1 7.1.1.2 7.1.1.3 7.1.2 7.2 7.2.1 7.2.1.1 7.2.1.2 7.2.1.3	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Gold MarketMarket Shares of International Mining and OilCompaniesMarket OrganizationsProducer AssociationsPetroleum Associations (OPEC, OAPEC)Copper Associations (CIPEC and Others)Bauxite Association (IBA)	 . 133 . 134 . 135 . 137 . 138 . 141 . 142 . 144 . 145 . 150 . 153 . 155
7.1 7.1.1 7.1.1 7.1.1.2 7.1.1.3 7.1.2 7.2 7.2.1 7.2.1.1 7.2.1.2 7.2.1.3 7.2.1.3 7.2.1.4	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Gold MarketThe Gold MarketMarket Shares of International Mining and OilCompaniesMarket OrganizationsProducer AssociationsPetroleum Associations (OPEC, OAPEC)Copper Associations (CIPEC and Others)Bauxite Association (IBA)Iron Ore Association (APEF)Tungsten Association (PTA)	 . 133 . 134 . 135 . 137 . 138 . 141 . 142 . 144 . 145 . 150 . 153 . 155 . 156
7.1 7.1.1 7.1.1 7.1.1.2 7.1.1.3 7.1.2 7.2 7.2.1 7.2.1.1 7.2.1.2 7.2.1.3 7.2.1.4 7.2.1.5 7.2.1.6	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Gold MarketThe Gold MarketMarket Shares of International Mining and OilCompaniesMarket OrganizationsProducer AssociationsPetroleum Associations (OPEC, OAPEC)Copper Associations (CIPEC and Others)Bauxite Association (IBA)Iron Ore Association (APEF)	 133 134 135 137 138 141 142 144 145 150 153 155 156 157
7.1 7.1.1 7.1.1 7.1.1.2 7.1.1.3 7.1.2 7.2 7.2.1 7.2.1.1 7.2.1.2 7.2.1.2 7.2.1.3 7.2.1.4 7.2.1.5	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Gold MarketThe Gold MarketMarket Shares of International Mining and OilCompaniesMarket OrganizationsProducer AssociationsPetroleum Associations (OPEC, OAPEC)Copper Associations (CIPEC and Others)Bauxite Association (IBA)Iron Ore Association (APEF)Tungsten Association (UI)Other Producer Associations	 133 134 135 137 138 141 142 144 145 150 153 155 156 157 158
7.1 7.1.1 7.1.1.1 7.1.1.2 7.1.1.3 7.1.2 7.2 7.2.1 7.2.1.1 7.2.1.2 7.2.1.2 7.2.1.3 7.2.1.4 7.2.1.5 7.2.1.6 7.2.1.7	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Gold MarketThe Gold MarketMarket Shares of International Mining and OilCompaniesMarket OrganizationsProducer AssociationsPetroleum Associations (OPEC, OAPEC)Copper Associations (CIPEC and Others)Bauxite Association (IBA)Iron Ore Association (APEF)Tungsten Association (VI)Uranium Association (UI)	 133 134 135 137 138 141 142 144 145 150 153 155 156 157 158 160
7.1 7.1.1 7.1.1 7.1.1.2 7.1.1.3 7.1.2 7.2 7.2.1 7.2.1.1 7.2.1.2 7.2.1.3 7.2.1.4 7.2.1.5 7.2.1.6 7.2.1.7 7.2.2 7.3	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Aluminum MarketThe Gold MarketMarket Shares of International Mining and OilCompaniesMarket OrganizationsProducer AssociationsPetroleum Associations (OPEC, OAPEC)Copper Associations (CIPEC and Others)Bauxite Association (IBA)Iron Ore Association (PTA)Uranium Association (UI)Other Producer AssociationsInternational Commodity AgreementsMineral Pricing	 133 134 135 137 138 141 142 144 145 150 155 156 157 158 160 166
7.1 7.1.1 7.1.1 7.1.1.2 7.1.1.3 7.1.2 7.2 7.2.1 7.2.1.1 7.2.1.2 7.2.1.3 7.2.1.4 7.2.1.5 7.2.1.6 7.2.1.7 7.2.2 7.3 7.3.1	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Gold MarketMarket Shares of International Mining and OilCompaniesMarket OrganizationsProducer AssociationsPetroleum Associations (OPEC, OAPEC)Copper Associations (CIPEC and Others)Bauxite Association (IBA)Iron Ore Association (APEF)Tungsten Association (VI)Other Producer AssociationsInternational Commodity AgreementsMineral PricingDetermination of Mineral Supply	 133 134 135 137 138 141 142 144 145 150 153 155 156 157 158 160 166 168
7.1 7.1.1 7.1.1 7.1.1.2 7.1.1.3 7.1.2 7.2 7.2.1 7.2.1.1 7.2.1.2 7.2.1.3 7.2.1.4 7.2.1.5 7.2.1.6 7.2.1.7 7.2.2 7.3	Market StructuresDetermination and Alteration of Market StructuresThe Tin MarketThe Aluminum MarketThe Aluminum MarketThe Gold MarketMarket Shares of International Mining and OilCompaniesMarket OrganizationsProducer AssociationsPetroleum Associations (OPEC, OAPEC)Copper Associations (CIPEC and Others)Bauxite Association (IBA)Iron Ore Association (PTA)Uranium Association (UI)Other Producer AssociationsInternational Commodity AgreementsMineral Pricing	 133 134 135 137 138 141 142 144 145 150 153 155 156 157 158 160 166 168 168

Contents

7.3.3	Competitive Prices
7.3.4	Producer Prices
7.4	Market Models and Forecasts
7.4.1	Types of Mineral-Market Models
7.4.2	Forecasting

Part III International Mineral Policies

8	Policies and Cooperation Programs of Inter-
	national Organizations
8.1	General Problems and Objectives
8.1.1	Objectives of Mineral Exporting Countries
8.1.2	Objectives of Mineral Importing Countries
8.1.3	Conflicting Aims and Possible Solutions
8.2	Mineral Policy of International Organizations 195
8.2.1	The League of Nations
8.2.2	The United Nations
8.2.2.1	UNCTAD I–VI
8.2.2.2	Integrated Program for Commodities
8.2.2.3	United Nations Conventions on the Law of the Sea 200
8.2.3	The International Energy Programme of the Organization
	for Economic Cooperation and Development 205
8.2.4	The European Community
8.2.4.1	Lomé I Convention
8.2.4.2	Lomé II Convention
8.2.4.3	Lomé III Convention
8.3	International Cooperation in Mineral Exploration
	and Exploitation
8.3.1	Cooperation Programs of International Institutions 212
8.3.2	The UNDP and the UN Revolving Fund
8.3.3	The World Bank
8.3.4	The European Community
9	Policies in Industrialized Countries
9.1	Government Programs
9.1.1	Programs for the Preservation and Enhancement of
	Domestic Mineral Production
9.1.2	Promoting Mineral Exploration
9.1.3	Promoting Mining Investments
9.1.4	Stockpile Programs
9.1.5	Promoting Mineral Trade
9.1.6	Promoting Mineral Research
9.2	Policies of Mining Companies
9.2.1	Investment Strategies
9.2.2	Improvements in Mineral Utilization

Contents

10	Policies and Special Problems in Developing Countries	. 234
10.1	Concession Policy	. 235
10.2	Participation Policy	. 236
10.3	Fiscal Policy	
10.4	Marketing Policy	
10.5	Importance of Small-Scale Mining in Developing	
	Countries	. 240
10.5.1	Definition and Characteristics of Small-Scale Mining	
10.5.2	Production of Small-Scale Mining	. 241
10.5.3	Advantages and Disadvantages of Small-Scale Mining	
10.5.4	Forms of Technical Cooperation in Small-Scale Mining	. 245
10.6	Effects of Mining in Developing Countries	. 246
10.6.1	Primary Effects	
10.6.2	Secondary Effects	
Referen	nces	. 253
Index		. 263