

# Contents

<b>1</b>	<b>Introduction to Mine Wastes</b> .....	<b>1</b>
1.1	Scope of the Book.....	1
1.2	Definitions.....	3
1.2.1	Mining Activities.....	3
1.2.2	Metals, Ores and Industrial Minerals.....	3
1.2.3	Mine Wastes.....	4
1.3	Mine Waste Production.....	9
1.4	Mine Wastes: Unwanted By-Products or Valuable Resources?.....	11
1.5	Mining and Environmental Impacts.....	13
1.5.1	Contamination and Pollution.....	13
1.5.2	Historic Mining.....	16
1.5.3	Present-Day Unregulated Mining.....	18
1.5.4	Regulation of Modern Mining.....	21
1.6	Rehabilitation of Mine Wastes and Mine Sites.....	24
1.7	Sources of Information.....	27
1.8	Summary.....	29
<b>2</b>	<b>Sulfidic Mine Wastes</b> .....	<b>31</b>
2.1	Introduction.....	31
2.2	Weathering of Sulfidic Mine Wastes.....	31
2.3	Acid Producing Reactions.....	32
2.3.1	Pyrite.....	32
2.3.2	Other Sulfides.....	41
2.3.3	Other Minerals.....	42
2.4	Acid Buffering Reactions.....	42
2.4.1	Silicates.....	43
2.4.2	Carbonates.....	45
2.4.3	Exchangeable Cations.....	47
2.4.4	Reaction Rates.....	47
2.5	Spontaneous Combustion of Pyritic Wastes.....	48
2.6	Formation and Dissolution of Secondary Minerals.....	50
2.6.1	Pre-Mining and Post-Mining Secondary Minerals.....	51
2.6.2	Solubility of Secondary Minerals.....	54
2.6.3	Acid Consumption and Production.....	55
2.6.4	Coatings and Hardpans.....	56

2.7	Acid Generation Prediction .....	57
2.7.1	Geological Modeling .....	57
2.7.2	Geological, Petrographic, Geochemical and Mineralogical Descriptions .....	58
2.7.3	Sampling .....	59
2.7.4	Geochemical Tests .....	60
2.7.5	Modeling the Oxidation of Sulfidic Waste Dumps .....	65
2.8	Monitoring Sulfidic Wastes .....	66
2.9	Environmental Impacts .....	68
2.10	Control of Sulfide Oxidation .....	70
2.10.1	Wet Covers .....	73
2.10.2	Dry Covers .....	73
2.10.3	Encapsulation, In-Pit Disposal and Mixing .....	78
2.10.4	Co-Disposal and Blending .....	78
2.10.5	Addition of Organic Wastes .....	79
2.10.6	Bactericides .....	80
2.11	Summary .....	80
<b>3</b>	<b>Mine Water .....</b>	<b>83</b>
3.1	Introduction .....	83
3.2	Sources of AMD .....	85
3.3	Characterization .....	87
3.3.1	Sampling and Analysis .....	87
3.4	Classification .....	89
3.4.1	Acid Waters .....	90
3.4.2	Extremely Acid Waters .....	91
3.4.3	Neutral to Alkaline Waters .....	92
3.4.4	Saline Waters .....	92
3.5	Processes .....	93
3.5.1	Microbiological Activity .....	93
3.5.2	Precipitation and Dissolution of Secondary Minerals .....	95
3.5.3	Coprecipitation .....	99
3.5.4	Adsorption and Desorption .....	99
3.5.5	Eh-pH Conditions .....	100
3.5.6	Heavy Metals .....	101
3.5.7	The Iron System .....	102
3.5.8	The Aluminium System .....	104
3.5.9	The Arsenic System .....	105
3.5.10	The Mercury System .....	106
3.5.11	The Sulfate System .....	107
3.5.12	The Carbonate System .....	108
3.5.13	pH Buffering .....	109
3.5.14	Turbidity .....	111
3.6	Prediction of Mine Water Composition .....	111
3.6.1	Geological Modeling .....	111
3.6.2	Mathematical and Computational Modeling .....	112
3.7	Field Indicators of AMD .....	113

3.8	Monitoring AMD	114
3.9	AMD from Sulfuric Waste Rock Dumps	117
3.9.1	Hydrology of Waste Rock Dumps	117
3.9.2	Weathering of Waste Rock Dumps	119
3.9.3	Temporal Changes to Dump Seepages	121
3.10	Environmental Impacts of AMD	122
3.11	AMD Management Strategies	125
3.12	Treatment of AMD	126
3.12.1	Neutralization	128
3.12.2	Other Chemical Treatments	131
3.12.3	Anoxic Limestone Drains	131
3.12.4	Wetlands	133
3.12.5	Adit Plugging	137
3.12.6	Ground Water Treatment	138
3.13	Summary	139
<b>4</b>	<b>Tailings</b>	<b>143</b>
4.1	Introduction	143
4.2	Tailings Characteristics	144
4.2.1	Process Chemicals	144
4.2.2	Tailings Liquids	145
4.2.3	Tailings Solids	146
4.3	Tailings Dams	147
4.3.1	Tailings Hydrogeology	148
4.3.2	AMD Generation	150
4.3.3	Tailings Dam Failures	152
4.3.4	Monitoring	158
4.3.5	Wet and Dry Covers	159
4.4	Thickened Discharge and Paste Technologies	159
4.5	Backfilling	161
4.6	Riverine and Lacustrine Disposal	162
4.7	Marine Disposal	163
4.8	Recycling	164
4.9	Summary	167
<b>5</b>	<b>Cyanidation Wastes of Gold-Silver Ores</b>	<b>171</b>
5.1	Introduction	171
5.2	Occurrences and Uses of Cyanide	171
5.3	Cyanide Chemistry	172
5.3.1	Free Cyanide	172
5.3.2	Simple Cyanide Compounds	174
5.3.3	Complexed Cyanide	174
5.4	Gold Extraction	175
5.4.1	Heap Leach Process	175
5.4.2	Vat/Tank Leach Process	176
5.5	Hydrometallurgical Wastes	177
5.6	Cyanide Analysis and Monitoring	178

5.7	Environmental Impacts .....	179
5.8	Cyanide Destruction .....	181
5.8.1	Natural Attenuation .....	182
5.8.2	Enhanced Natural Attenuation .....	184
5.8.3	Engineered Attenuation .....	185
5.9	Summary .....	185
<b>6</b>	<b>Radioactive Wastes of Uranium Ores .....</b>	<b>189</b>
6.1	Introduction .....	189
6.2	Mineralogy and Geochemistry of Uranium .....	189
6.2.1	Uranium Ores .....	189
6.2.2	Placer and Beach Sands .....	190
6.3	Aqueous Chemistry of Uranium .....	191
6.3.1	Oxidative Dissolution of Uranium Minerals .....	191
6.3.2	Uranium Solubility .....	192
6.3.3	Uranium Precipitation .....	193
6.4	Radioactivity .....	194
6.4.1	Principles of Radioactivity .....	194
6.4.2	Radioactive Decay of Uranium and Thorium .....	196
6.4.3	Units and Measurements of Radioactivity and Radiation Dose .....	198
6.4.4	Radioactive Equilibrium and Disequilibrium .....	200
6.5	Uranium Mining and Extraction .....	201
6.5.1	Conventional Mining and Extraction .....	201
6.5.2	In Situ Leach (ISL) Operations .....	203
6.6	Mining, Processing and Hydrometallurgical Wastes .....	205
6.7	Tailings .....	207
6.7.1	Tailings Radioactivity .....	208
6.7.2	Tailings Solids .....	209
6.7.3	Tailings Liquids .....	210
6.7.4	Tailings Disposal .....	211
6.7.5	Long-term Stability of Tailings Dams .....	213
6.8	Mine Water .....	215
6.8.1	Constituents .....	215
6.8.2	Treatment .....	216
6.9	Monitoring .....	218
6.10	Radiation Hazards .....	219
6.10.1	Radiation Dose and Human Health .....	219
6.10.2	Occupational Radiation Exposure .....	221
6.11	Environmental Impacts .....	223
6.12	Summary .....	227
<b>7</b>	<b>Wastes of Phosphate and Potash Ores .....</b>	<b>231</b>
7.1	Introduction .....	231
7.2	Potash Mine Wastes .....	231
7.2.1	Potash Ores .....	232
7.2.2	Mining and Processing Wastes .....	232

73	Phosphate Mine Wastes.....	233
7.3.1	Phosphate Rock.....	233
7.3.2	Mining, Processing and Hydrometallurgical Wastes.....	235
7.3.3	Phosphogypsum.....	238
7.3.4	Disposal of Phosphogypsum.....	241
7.3.5	Potential Hazards and Environmental Impacts.....	246
7.4	Summary.....	248
	<b>References.....</b>	<b>251</b>
	<b>Subject Index</b>	<b>271</b>