

Contents

1	Introduction to Mine Wastes	1
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?	12
1.5	Mining and Environmental Impacts	15
1.5.1	Contamination and Pollution	21
1.5.2	Historic Mining	22
1.5.3	Present-Day Unregulated Mining	28
1.5.4	Regulation of Modern Mining	31
1.6	Rehabilitation of Mine Wastes and Mine Sites	33
1.7	Sources of Information	38
1.8	Summary	40
2	Sulfidic Mine Wastes	43
2.1	Introduction	43
2.2	Weathering of Sulfidic Mine Wastes	45
2.3	Acid Producing Reactions	46
2.3.1	Pyrite	46
2.3.2	Other Sulfides	57
2.3.3	Other Minerals	59
2.4	Acid Buffering Reactions	60
2.4.1	Silicates	61
2.4.2	Carbonates	63
2.4.3	Exchangeable Cations	64
2.4.4	Reaction Rates	64
2.5	Coal Mine Wastes	66
2.5.1	Spontaneous Combustion of Pyritic Wastes	68

2.6	Formation and Dissolution of Secondary Minerals	70
2.6.1	Pre-mining and Post-mining Secondary Minerals	70
2.6.2	Solubility of Secondary Minerals	76
2.6.3	Acid Consumption and Production	77
2.6.4	Coatings and Hardpans	78
2.7	Acid Generation Prediction	80
2.7.1	Geological Modeling	80
2.7.2	Geological, Petrographic, Geochemical and Mineralogical Descriptions	81
2.7.3	Sampling	82
2.7.4	Geochemical Tests	83
2.7.5	Modeling the Oxidation of Sulfidic Waste Dumps	91
2.8	Monitoring Sulfidic Wastes	92
2.9	Environmental Impacts	94
2.9.1	Soil and Sediment Contamination	95
2.9.2	Plant Colonization	101
2.10	Control of Sulfide Oxidation	102
2.10.1	Wet Covers	105
2.10.2	Dry Covers	106
2.10.3	Encapsulation, In-Pit Disposal and Mixing	111
2.10.4	Co-disposal and Blending	112
2.10.5	Addition of Organic Wastes	113
2.10.6	Bactericides	114
2.11	Summary	115
3	Mine Water	119
3.1	Introduction	119
3.2	Sources of AMD	122
3.3	Characterization	125
3.3.1	Sampling and Analysis	126
3.4	Classification	128
3.4.1	Acid Waters	130
3.4.2	Extremely Acid Waters	132
3.4.3	Neutral to Alkaline Waters	132
3.4.4	Coal Mine Waters	133
3.5	Processes	133
3.5.1	Microbiological Activity	134
3.5.2	Precipitation and Dissolution of Secondary Minerals	136
3.5.3	Coprecipitation	141
3.5.4	Adsorption and Desorption	141
3.5.5	Eh-pH Conditions	143
3.5.6	Heavy Metals	144
3.5.7	The Iron System	146
3.5.8	The Aluminium System	150
3.5.9	The Arsenic System	152

3.5.10	The Mercury System	154
3.5.11	The Sulfate System	154
3.5.12	The Carbonate System	156
3.5.13	pH Buffering	157
3.5.14	Turbidity	159
3.6	Prediction of Mine Water Composition	159
3.6.1	Geological Modeling	159
3.6.2	Mathematical and Computational Modeling	160
3.7	Field Indicators of AMD	162
3.8	Monitoring AMD	162
3.9	AMD from Sulfidic Waste Rock Dumps	169
3.9.1	Hydrology of Waste Rock Dumps	170
3.9.2	Weathering of Waste Rock Dumps	171
3.9.3	Temporal Changes to Dump Seepages	173
3.10	Environmental Impacts	174
3.10.1	Surface Water Contamination	175
3.10.2	Impact on Aquatic Life	176
3.10.3	Sediment Contamination	176
3.10.4	Ground Water Contamination	177
3.10.5	Climate Change	179
3.11	AMD Management Strategies	179
3.12	Treatment of AMD	180
3.12.1	Active Neutralization	186
3.12.2	Other Chemical Treatments	189
3.12.3	Passive Neutralization	190
3.12.4	Wetlands	192
3.12.5	Bioreactors	198
3.12.6	Adit Plugging	199
3.12.7	Ground Water Treatment	199
3.13	Summary	201
4	Tailings	205
4.1	Introduction	205
4.2	Tailings Characteristics	206
4.2.1	Process Chemicals	206
4.2.2	Tailings Liquids	208
4.2.3	Tailings Solids	208
4.3	Tailings Dams	210
4.3.1	Tailings Hydrogeology	212
4.3.2	AMD Generation	214
4.3.3	Tailings Dam Failures	217
4.3.4	Monitoring	224
4.3.5	Wet and Dry Covers	225
4.4	Thickened Discharge and Paste Technologies	226
4.5	Backfilling	227

4.6	Riverine and Lacustrine Disposal	229
4.7	Marine Disposal	233
4.8	Recycling and Reuse	237
4.9	Summary	239
5	Cyanidation Wastes of Gold-Silver Ores	243
5.1	Introduction	243
5.2	Occurrences and Uses of Cyanide	243
5.3	Cyanide Chemistry	245
5.3.1	Free Cyanide	246
5.3.2	Simple Cyanide Compounds	247
5.3.3	Complexed Cyanide	247
5.4	Gold Extraction	248
5.4.1	Heap Leach Process	248
5.4.2	Vat/Tank Leach Process	249
5.5	Hydrometallurgical Wastes	250
5.6	Cyanide Analysis and Monitoring	251
5.7	Environmental Impacts	252
5.8	Cyanide Destruction	256
5.8.1	Natural Attenuation	257
5.8.2	Enhanced Natural Attenuation	259
5.8.3	Engineered Attenuation	260
5.9	Summary	261
6	Radioactive Wastes of Uranium Ores	263
6.1	Introduction	263
6.2	Mineralogy and Geochemistry of Uranium	263
6.2.1	Uranium Ores	263
6.2.2	Placer and Beach Sands	264
6.3	Aqueous Chemistry of Uranium	265
6.3.1	Oxidative Dissolution of Uranium Minerals	265
6.3.2	Uranium Solubility	267
6.3.3	Uranium Precipitation	268
6.4	Radioactivity	269
6.4.1	Principles of Radioactivity	269
6.4.2	Radioactive Decay of Uranium and Thorium	270
6.4.3	Units and Measurements of Radioactivity and Radiation Dose	273
6.4.4	Radioactive Equilibrium and Disequilibrium	275
6.5	Uranium Mining and Extraction	276
6.5.1	Conventional Mining and Extraction	277
6.5.2	In Situ Leach (ISL) Operations	278
6.6	Mining, Processing and Hydrometallurgical Wastes	283
6.7	Tailings	284
6.7.1	Tailings Radioactivity	284
6.7.2	Tailings Solids	285

6.7.3	Tailings Liquids	287
6.7.4	Tailings Disposal	288
6.7.5	Long-Term Stability of Tailings Dams	290
6.8	Mine Water	292
6.8.1	Constituents	292
6.8.2	Treatment	293
6.9	Monitoring	295
6.10	Radiation Hazards	296
6.10.1	Radiation Dose and Human Health	297
6.10.2	Occupational Radiation Exposure	298
6.11	Environmental Impacts	301
6.11.1	Excessive Radioactivity Levels and Radon Emissions	305
6.11.2	Inappropriate Use of Tailings and Waste Rocks	306
6.11.3	Failure of Tailings Dams	306
6.11.4	Soil and Sediment Contamination	306
6.11.5	Ground and Surface Water Contamination	308
6.11.6	Acid Mine Drainage	309
6.12	Summary	309
7	Wastes of Phosphate and Potash Ores	313
7.1	Introduction	313
7.2	Potash Mine Wastes	313
7.2.1	Potash Ores	314
7.2.2	Mining and Processing Wastes	314
7.3	Phosphate Mine Wastes	315
7.3.1	Phosphate Rock	315
7.3.2	Mining, Processing and Hydrometallurgical Wastes	317
7.3.3	Phosphogypsum	320
7.3.4	Disposal of Phosphogypsum	323
7.3.5	Potential Hazards and Environmental Impacts	329
7.4	Summary	332
	References	335
	Index	393

Table G.3 Weight based concentrations

Unit	Symbol
Parts per million	$\text{ppm} = \text{mg kg}^{-1}$
Parts per billion	$\text{ppb} = \text{ug kg}^{-1}$
Weight percent	$\text{wt\%} = (\text{mg kg}^{-1}) \times 100$