

Preface	V
Introduction	1
What are ore deposits?	1
Mining in the stress field between society and environment	2
The mineral resources conundrum.....	4
 Part I Metalliferous Ore Deposits	
 1 Geological ore formation process systems (metallogenesis)	5
Synopsis	5
1.1 Magmatic Ore Formation Systems	9
1.1.1 Orthomagmatic ore formation.....	10
1.1.2 Ore deposits related to ocean floor volcanism (ophiolite hosted Cyprus type Zn-Cu-Au).....	21
1.1.3 Ore formation related to alkaline igneous rocks, carbonatites and kimberlites.....	26
1.1.4 Granites – The Earth’s workhorses of ore formation.....	29
1.1.5 Ore deposits in pegmatites: Sources of high-technology rare and “green” metals	37
1.1.6 Hydrothermal ore formation	42
Isotope geochemistry	47
Fluid Inclusions: Temperature and pressure	53
Mineral succession: Ore microscopy to EPMA	56
Hydrothermal Host Rock Alteration	59
1.1.7 Hydrothermal vein deposits.....	62
1.1.8 Skarn- and contact-metasomatic ore deposits.....	68
1.1.9 Volcanogenic ore deposits – Gold, iron and base metals.....	70
Subvolcanic porphyry copper	71
Terrestrial volcanic epithermal Au and Ag	76
Submarine volcanogenic massive sulfides	79
1.2 Supergene Ore Formation Systems	82
1.2.1 Residual, or eluvial ore deposits.....	85
1.2.2 Supergene enrichment by descending solutions	87
1.2.3 Infiltration as an agent of ore formation.....	92
1.3 Sedimentary Ore Formation Systems	95
1.3.1 Organic-rich shales in metallogenesis.....	97
1.3.2 Placer deposits	98
1.3.3 Autochthonous iron and manganese deposits.....	102
1.3.4 Sediment-hosted, submarine-exhalative (sedex) deposits.....	109
1.4 Diagenetic Ore Formation Systems	112
1.4.1 The European Copper Shale.....	116
1.4.2 Diagenetic-hydrothermal carbonate-hosted Pb-Zn deposits	118
1.4.3 Diagenetic hydrothermal-metasomatic ore deposits	121
1.4.4 Diagenetic-hydrothermal ore formation related to salt diapirs.....	123
1.5 Metamorphosed and Metamorphic Ore Deposits	125
1.6 Metamorphogenic Ore Formation Systems	129
1.7 Metallogeny – Ore Deposit Formation in Space and Time	136

1.7.1	Metallogenetic space and time concepts	137
1.7.2	Metallogeny and lid tectonics (4500 to ~2500 Ma)	139
1.7.3	Metallogeny and plate tectonics (~2500 Ma to the present)	139
1.8	Genetic Classification of Ore and Mineral Deposits	151
1.9	Metallogenesis: Summary and Further Reading	154
2	Economic geology of metals	157
	Synopsis	157
2.1	The Iron and Steel Metals	157
2.1.1	Iron	157
2.1.2	Manganese	168
2.1.3	Chromium	172
2.1.4	Nickel	177
2.1.5	Cobalt	184
2.1.6	Molybdenum	186
2.1.7	Tungsten (wolfram)	191
2.1.8	Vanadium	195
2.2	Base Metals	197
2.2.1	Copper	197
2.2.2	Lead and zinc	210
2.2.3	Tin	218
2.3	Precious Metals	224
2.3.1	Gold	240
2.3.2	Silver	240
2.3.3	Platinum and platinum group metals	246
2.4	Light Metals	251
2.4.1	Aluminium	251
2.4.2	Magnesium	256
2.5	Minor and Speciality Metals	258
2.5.1	Mercury	258
2.5.2	Antimony	261
2.5.3	Arsenic	264
2.5.4	Electronic metals (selenium, tellurium, gallium, germanium, indium, cadmium) and silicon	267
2.5.5	Bismuth	270
2.5.6	Zirconium and hafnium	271
2.5.7	Titanium	271
2.5.8	Rare earth elements (REE, lanthanides)	277
2.5.9	Niobium and tantalum	282
2.5.10	Lithium	289
2.5.11	Beryllium	292
2.5.12	Uranium (and thorium)	295
2.6	Metals: Summary and Further Reading	309

Part II Non-Metallic Minerals and Rocks

3	Industrial minerals, earths and rocks	311
	Synopsis	311
3.1	Andalusite, kyanite and sillimanite	312
3.2	Asbestos	315
3.3	Barite and celestite	318
3.4	Bentonite (smectite rocks)	322

3.5	Borates	325
3.6	Carbonate rocks: limestone, calcite marble, marlstone, dolomite	328
3.7	Clay and clay rocks	331
3.8	Diamond	334
3.9	Diatomite and tripoli	342
3.10	Feldspar and feldspar-rich igneous rocks	343
3.11	Fluorite	345
3.12	Graphite	349
3.13	Gypsum and anhydrite	352
3.14	Kaolin	355
3.15	Magnesite	358
3.16	Mica (muscovite, phlogopite, vermiculite)	364
3.17	Olivine (dunite)	367
3.18	Phosphate (apatite)	369
3.19	Quartz and silicon	373
3.20	Quartzite	375
3.21	Quartz sand and gravel	377
3.22	Sodium carbonate, sodium sulfate and alum salts	380
3.23	Sulfur	381
3.24	Talc and pyrophyllite	384
3.25	Volcaniclastic rocks	388
3.26	Wollastonite	390
3.27	Zeolites	392
3.28	Industrial Minerals and Rocks: Summary and Further Reading	394
4	Salt deposits (evaporites)	397
	Synopsis	397
4.1	Salt Minerals and Salt Rocks	399
4.2	The Formation of Salt Deposits	405
	4.2.1 Salt formation today	405
	4.2.2 Salt formation in the geological past	413
4.3	Post-Depositional Fate of Salt Rocks	425
	4.3.1 Diagenesis and metamorphism of evaporites	425
	4.3.2 Deformation of salt rocks	428
	4.3.3 Halokinesis and salt tectonics	430
	4.3.4 Supergene alteration of salt deposits	435
4.4	From Exploration to Salt Mining	437
	4.4.1 Exploration and development of salt deposits	437
	4.4.2 Geological practice in salt mining	439
4.5	Salt: Summary and Further Reading	441

Part III The Practice of Economic Geology

5	Geological concepts and methods in the mining cycle:	
	Exploration, exploitation and closure of mines	443
	Synopsis	443
5.1	Economic Considerations	444
5.2	The Search for Mineral Deposits (Exploration)	446
	5.2.1 Pre-exploration stage	446
	5.2.2 Geological exploration	448
	5.2.3 Geological remote sensing	451
	5.2.4 Geochemical exploration	454

	5.2.5	Geophysical exploration	460
	5.2.6	Trenching and drilling	466
5.3		Development and Valuation of Mineral Deposits	470
	5.3.1	Geological mapping and sampling	470
	5.3.2	Ore reserve estimation and determination of grade	473
	5.3.3	Valuation of mineral deposits	479
5.4		Mining and the Environment	481
	5.4.1	Potential environmental problems related to mining	482
	5.4.2	Waste rock, tailings and seepage water	487
	5.4.3	Mining and climate change	488
	5.4.4	Mine closure	489
5.5		Deep Geological Disposal of Dangerous Waste	492
5.6		The Practice of Economic Geology: Summary and Further Reading	495

Part IV Fossil Energy Raw Materials – Coal, Oil and Gas

6	Coal	500
	Synopsis	500
6.1	The Substance of Coal.	505
	6.1.1 Coal types, rank and grade	505
	6.1.2 Petrography of coal: lithotypes and macerals	508
	6.1.3 The chemical composition of coal	511
6.2	Peat Formation and Coal Deposits	519
	6.2.1 Types and dimensions of coal seams	519
	6.2.2 Concordant and discordant clastic sediments in coal seams	522
	6.2.3 Peat formation environments	522
	6.2.4 Host rocks of coal	526
	6.2.5 Marker beds in coal formations	527
	6.2.6 Coal formation in geological space and time	528
6.3	The Coalification Process	528
	6.3.1 Biochemical peatification	528
	6.3.2 Geochemical coalification	530
	6.3.3 Measuring the degree of coalification	531
	6.3.4 Causes of coalification	532
	6.3.5 Coal maturity and diagenesis of country rocks	535
6.4	Post-Depositional Changes of Coal Seams	535
	6.4.1 Tectonic deformation	535
	6.4.2 Epigenetic mineralization of coal seams	536
	6.4.3 Exogenetic alteration of coal	536
6.5	Applications of Coal Geology	537
	6.5.1 Exploration	537
	6.5.2 Reserve estimation	540
	6.5.3 Coal mining geology	541
	6.5.4 Environmental aspects of coal mining	543
6.6	Coal: Summary and Further Reading	547
7	Petroleum and Natural Gas Deposits	551
	Synopsis	551
7.1	Species of Natural Bitumens, Gas and Kerogen, and their Properties	553
	7.1.1 Crude oil, or petroleum	554
	7.1.2 Natural gas	556
	7.1.3 Natural gas hydrates (clathrates)	559

7.1.4	Tar	560
7.1.5	Earth wax (ozocerite)	560
7.1.6	Pyrobitumen	560
7.1.7	Natural asphalt	560
7.1.8	Kerogen	560
7.2	The Origin of Petroleum and Natural Gas	562
7.2.1	Petroleum source rocks	563
7.2.2	Dry gas source rocks	565
7.2.3	Eogenesis and catagenesis of kerogen	566
7.2.4	The oil window	569
7.3	Formation of Petroleum and Natural Gas Deposits	570
7.3.1	Migration	571
7.3.2	Conventional and unconventional reservoir rocks	573
7.3.3	Petroleum and gas traps	575
7.3.4	Formation and reservoir waters	581
7.3.5	Alteration of petroleum in reservoirs (degradation)	582
7.3.6	Tectonic environments and age of hydrocarbon provinces	583
7.4	Exploring for Petroleum and Natural Gas Deposits	584
7.4.1	Geophysical methods	586
7.4.2	Geochemical methods of hydrocarbon exploration	587
7.4.3	Exploration drilling	587
7.4.4	Geophysical borehole measurements	588
7.5	The Exploitation of Petroleum and Natural Gas Deposits	592
7.5.1	Reservoir conditions	592
7.5.2	Oil and gasfield development	594
7.5.3	Oil and gas production	596
7.5.4	Petroleum mining	599
7.5.5	Reserve and Resource Estimation	599
7.5.6	Post-production uses of oil and gas fields	601
7.6	Tar, Asphalt, Pyrobitumen and Shungite	601
7.7	Immature Oil Shales	604
7.8	Environmental Aspects of Oil and Gas Production	605
7.8.1	Water resources protection	608
7.8.2	Subsidence, and induced (man-made) seismic activity	608
7.8.3	Hydrocarbons and climate	609
7.9	Hydrocarbons: Summary and Further Reading	609
	Color Plates	613
	The New Age of Economic Geology – Epilogue	645
	References, General Index, Location Index, Box Titles	647
	This book has a companion website: www.schweizerbart.de	