

Contents

Preface	page xiii
Figure credits	xvii
Praise for the first edition	xxi
Part I Minerals as chemical compounds	1
1 Subject and history of mineralogy	3
1.1 What is mineralogy?	3
1.2 History	3
1.3 Major directions of investigation	8
1.4 Some preliminary advice	9
1.5 Definition of crystal and mineral	10
1.6 Summary	10
2 Elements, bonding, simple structures, and ionic radii	12
2.1 Chemical elements	12
2.2 Bonding	15
2.3 Ionic radii	22
2.4 Radius ratio and coordination polyhedra	24
2.5 Some general rules concerning ionic structures	29
2.6 Summary	29
3 Isomorphism, solid solutions, and polymorphism	31
3.1 Isomorphism and solid solutions	31
3.2 Polymorphism and phase transitions	32
3.3 Summary	36
4 Chemical formulas of minerals	37
4.1 Ideal formulas	37
4.2 Empirical formulas	37
4.3 Calculation of chemical formulas from weight percentage of oxides	37
4.4 Simplified formulas	38
4.5 How to use ternary diagrams	39
4.6 Summary	41
5 Chemical classification and names of minerals	42
5.1 Minerals, mineral species, and mineral varieties	42
5.2 Chemical classification of minerals	42
5.3 Mineral names	47
5.4 Summary	47
6 Mineral identification of hand specimens	49
6.1 Different scales	49
6.2 State of aggregation (including crystallographic form and habit)	49

6.3	Color, streak, and luster	50
6.4	Mechanical properties	51
6.5	Density and specific gravity	54
6.6	Other properties	54
6.7	Associations of minerals	54
6.8	Some directions for practical mineral identification	54
6.9	Summary	56
Part II Symmetry expressed in crystal structures and morphology		59
7	The concept of a lattice and description of crystal structures	61
7.1	Discovery of the lattice	61
7.2	Symmetry considerations	63
7.3	The unit cell as the basic building block of a crystal	64
7.4	Representation of lattice lines and planes with rational indices	72
7.5	Relations between lattice planes and lattice lines	76
7.6	Crystal structure	78
7.7	Summary	80
8	Crystal symmetries: point-groups and space-groups	81
8.1	Introduction	81
8.2	Spherical representations of morphology	81
8.3	Point-group symmetry	89
8.4	Crystallographic forms	100
8.5	Some comments on space-groups	102
8.6	Summary	106
9	Crystalline defects	108
9.1	Types of defects	108
9.2	Point defects	108
9.3	Dislocations (line defects)	108
9.4	Planar defects during growth	110
9.5	Planar defects during phase transformations	111
9.6	Quasicrystals	116
9.7	Radiation defects and radioactive decay	116
9.8	Summary	117
10	Crystal growth and aggregation	118
10.1	Crystal habit	118
10.2	Nucleation and growth	120
10.3	Various growth effects	125
10.4	Aggregation	127
10.5	Summary	128
Part III Physical investigation and properties of minerals		131
11	X-ray diffraction	133
11.1	Basic concepts	133
11.2	Brief discussion of waves	136
11.3	Laue and Bragg equations	137
11.4	The powder method	141

11.5	Crystal identification with the powder method	143
11.6	X-rays and crystal structure	143
11.7	Additional atomic scattering considerations	146
11.8	Summary	146
12	Physical properties	149
12.1	Vectors and tensors: general issues	149
12.2	Symmetry considerations	151
12.3	Tensors of different ranks	152
12.4	Density	152
12.5	Thermal conductivity, thermal expansion, and specific heat	154
12.6	Elastic properties	155
12.7	Piezoelectricity and pyroelectricity	159
12.8	Magnetic properties	160
12.9	Summary	164
13	Optical properties	166
13.1	Some physical background	166
13.2	Refractive index and optical applications	168
13.3	Polarization and birefringence	173
13.4	The optical indicatrix	180
13.5	Dispersion	185
13.6	Pleochroism	186
13.7	Summary	187
14	Mineral identification with the petrographic microscope	189
14.1	Sample preparation	189
14.2	Microscope alignment	190
14.3	Determination of the refractive index	191
14.4	Use of interference colors	191
14.5	Observation of interference figures with convergent light	196
14.6	Characteristics of important rock-forming minerals	202
14.7	Summary	215
15	Color	217
15.1	Overview	217
15.2	Absorption	217
15.3	Fluorescence and phosphorescence	221
15.4	Dispersion	222
15.5	Luster	222
15.6	Microstructure	222
15.7	Summary	223
16	Advanced analytical methods	225
16.1	Overview	225
16.2	High-resolution imaging	226
16.3	Diffraction	234
16.4	Spectroscopic methods	238
16.5	Summary	248

17 Mechanical properties and deformation	251
17.1 Stress–strain	251
17.2 Deformation by slip	252
17.3 Dislocation microstructures	254
17.4 Mechanical twinning	254
17.5 Polycrystal plasticity	256
17.6 Summary	256
Part IV Mineral-forming processes	259
18 Mineral genesis	261
18.1 Overview	261
18.2 Mineral-forming environments	261
18.3 Types of mineral crystallization	264
18.4 Types of mineral deposits	265
18.5 Multistage processes, generations, and parageneses	267
18.6 Typomorphism of minerals	267
18.7 Summary	269
19 Considerations of thermodynamics	270
19.1 Background	270
19.2 Energy minimum in a system	271
19.3 The simplest thermodynamic calculations and diagrams	272
19.4 Electrolytes and Eh–pH phase diagrams	278
19.5 Phase rule	282
19.6 Summary	283
20 Phase diagrams	284
20.1 Introduction	284
20.2 Diagrams for crystallization from a melt	284
20.3 Pressure–temperature phase diagrams and implications for the Earth mantle	285
20.4 Melting behavior of solid solutions	286
20.5 Exsolution	289
20.6 Summary	290
Part V A systematic look at mineral groups	293
21 Important information about silica minerals and feldspars. Their occurrence in granites and pegmatites	295
21.1 Silica minerals	295
21.2 Feldspars	299
21.3 Brief description of silica minerals	307
21.4 Brief description of feldspars	309
21.5 The origin of granite	311
21.6 Pegmatites	315
21.7 Summary	315
22 Simple compounds. Unusual mineral occurrences	317
22.1 Background about metals and intermetallics	317
22.2 Crystal structures and relationships to morphology and physical properties	317
22.3 Brief description of important minerals of the native elements	321

Contents

ix

22.4	Unusual conditions of formation	323
22.5	Summary	324
23	Halides. Evaporite deposits	325
23.1	Common compositional and structural features of halides	325
23.2	Brief description of halide minerals	327
23.3	Origin of halide minerals	327
23.4	Commercial deposits	334
23.5	Summary	334
24	Carbonates and other minerals with triangular anion groups. Sedimentary origins	336
24.1	Characteristic features of composition and crystal chemistry of carbonates and borates	336
24.2	Morphology and properties of carbonates	340
24.3	Brief description of important carbonate minerals	340
24.4	Formation conditions of carbonates	342
24.5	Carbonates in sedimentary rocks: chemical and biological origins	344
24.6	Summary	349
25	Phosphates, sulfates, and related minerals. Apatite as a biogenic mineral	350
25.1	Phosphates, arsenates, and vanadates	350
25.2	Brief description of important phosphate minerals	350
25.3	Sulfates and tungstates	352
25.4	Brief description of important sulfate and tungstate minerals	352
25.5	Biogenic processes	356
25.6	Summary	360
26	Sulfides and related minerals. Hydrothermal processes	361
26.1	Crystal chemistry	361
26.2	Brief description of important sulfide minerals	365
26.3	Sulfide genesis and hydrothermal deposits	368
26.4	Weathering and oxidation of sulfides	374
26.5	Summary	375
27	Oxides and hydroxides. Review of ionic crystals	377
27.1	Overview	377
27.2	Ionic crystal structures	377
27.3	More complex oxide structures	382
27.4	Brief description of important oxide and hydroxide minerals	385
27.5	Summary	394
28	Orthosilicates and ring silicates. Metamorphic mineral assemblages	396
28.1	General comments on silicates	396
28.2	Orthosilicates	399
28.3	Brief description of important orthosilicate minerals	405
28.4	Ring silicates	409
28.5	Brief description of important ring silicate minerals	409
28.6	Metamorphic minerals	410
28.7	Summary	417

29 Sheet silicates. Weathering of silicate rocks	418
29.1 Basic structural features	418
29.2 Polytypism	423
29.3 Structure of clay minerals	425
29.4 Brief description of important sheet silicate minerals	426
29.5 Formation conditions for sheet silicates and weathering of silicate rocks	431
29.6 Clay minerals in soils	431
29.7 Summary	435
30 Chain silicates. Discussion of some igneous and metamorphic processes	437
30.1 Structural and chemical features	437
30.2 Brief description of important chain silicate minerals	445
30.3 Crystallization of igneous rocks	450
30.4 Metamorphic reactions in siliceous limestones	456
30.5 Summary	460
31 Framework silicates. Zeolites and ion exchange properties of minerals	462
31.1 The framework structure	462
31.2 Morphology and physical properties	464
31.3 Brief description of important framework silicate minerals	468
31.4 Ion exchange properties of some minerals	469
31.5 Summary	471
32 Organic minerals	473
32.1 Organic compounds	473
32.2 Chemical classes and some structures of organic minerals	474
32.3 Brief descriptions of some organic minerals	475
32.4 Summary	477
Part VI Applied mineralogy	479
33 Metalliferous mineral deposits	481
33.1 Applied mineralogy	481
33.2 Economically important minerals	482
33.3 Geological setting of metal deposits	482
33.4 Metal production around the world	489
33.5 Reserves	498
33.6 Summary	500
34 Gemstones	501
34.1 General comments about gems	501
34.2 Instruments used by gemologists	504
34.3 Important gems	507
34.4 Gemstone enhancements	510
34.5 Crystal synthesis	512
34.6 Summary	517
35 Cement minerals	518
35.1 Significance of cement	518
35.2 Some features of nonhydraulic cements	519
35.3 Portland cement	519

Contents

xi

35.4 Some problems with concrete	522
35.5 Summary	524
36 Minerals and human health	526
36.1 Mineral-like materials in the human body	526
36.2 Minerals in nutrition	526
36.3 Minerals as health hazards	529
36.4 Summary	535
37 Mineral composition of the solar system	536
37.1 Elements in the universe	536
37.2 Minerals of meteorites	538
37.3 Minerals of the planets	542
37.4 Minerals of the Moon	546
37.5 Summary	549
38 Mineral composition of the Earth	551
38.1 Chemical composition of the Earth	551
38.2 Composition of the crust	551
38.3 Composition of the mantle	553
38.4 Composition of the inner core	557
38.5 Atmosphere and hydrosphere	558
38.6 Mineral evolution over Earth's history	558
38.7 Microscopic mineralogy	560
38.8 Summary	561
Appendices	563
1a.1 Metallic or submetallic luster, no cleavage or poor cleavage, sorted according to hardness	564
1a.2 Metallic or submetallic luster, distinct cleavage, sorted according to hardness	565
1b.1 Nonmetallic luster, no cleavage or poor cleavage, sorted according to hardness	566
1b.2 Nonmetallic luster, single cleavage (platy), sorted according to hardness	568
1b.3 Nonmetallic luster, polyhedral cleavage (three systems), sorted according to hardness	570
1b.4 Nonmetallic luster, prismatic or fibrous cleavage (two systems), sorted according to hardness	572
2 Minerals that display some distinctive physical properties	574
3 Rock-forming minerals that are colored in thin section	575
4a Optically isotropic minerals, sorted according to refractive index	576
4b Minerals with very low birefringence (up to white interference colors in 30 µm thin sections), sorted according to birefringence	577
4c Minerals with low birefringence (up to first-order red interference colors in 30 µm thin sections), sorted according to birefringence	578
4d Minerals with high birefringence (second- to fourth-order interference colors in 30 µm thin sections), sorted according to birefringence	579
4e Minerals with very high birefringence (higher than third-order interference colors in 30 µm thin sections), sorted according to birefringence	581
Glossary	582
References	590
Index	603

Color plates section is found between pp. 314 and 315