
Contents

| | |
|---|----|
| Introduction | 1 |
| Part I | |
| Biogeochemistry of the Human Environment | 3 |
| I-1 The Biosphere | 5 |
| I-2 Soils | 9 |
| I-3 Waters | 39 |
| I-4 Air | 47 |
| I-5 Plants | 57 |
| I-6 Humans | 67 |
| Part II | |
| Biogeochemistry of Trace Elements | 85 |
| II-1 Trace Elements of Group 1 (Previously Group Ia) | 87 |
| II-1.1 Lithium (Li) | 87 |
| II-1.1.1 Introduction | 87 |
| II-1.1.2 Production and Use | 89 |
| II-1.1.3 Soils | 89 |
| II-1.1.4 Waters | 90 |
| II-1.1.5 Air | 90 |
| II-1.1.6 Plants | 91 |
| II-1.1.7 Humans and Animals | 92 |
| II-1.2 Rubidium (Rb) | 93 |
| II-1.2.1 Introduction | 93 |
| II-1.2.2 Production and Use | 94 |
| II-1.2.3 Soils | 94 |
| II-1.2.4 Waters | 94 |

| | | |
|----------|---|-----|
| II-1.2.5 | Air | 95 |
| II-1.2.6 | Plants | 95 |
| II-1.2.7 | Humans and Animals | 96 |
| II-1.3 | Cesium (Cs) | 97 |
| II-1.3.1 | Introduction | 97 |
| II-1.3.2 | Production and Use | 97 |
| II-1.3.3 | Soils | 97 |
| II-1.3.4 | Waters | 98 |
| II-1.3.5 | Air | 98 |
| II-1.3.6 | Plants | 99 |
| II-1.3.7 | Humans | 99 |
| II-1.3.8 | Cesium-137 | 100 |
| II-2 | Trace Elements of Group 2 (Previously Group IIa) | 105 |
| II-2.1 | Beryllium (Be) | 105 |
| II-2.1.1 | Introduction | 105 |
| II-2.1.2 | Production and Use | 107 |
| II-2.1.3 | Soils | 107 |
| II-2.1.4 | Waters | 108 |
| II-2.1.5 | Air | 109 |
| II-2.1.6 | Plants | 110 |
| II-2.1.7 | Humans | 111 |
| II-2.2 | Strontium (Sr) | 112 |
| II-2.2.1 | Introduction | 112 |
| II-2.2.2 | Production and Use | 113 |
| II-2.2.3 | Soils | 113 |
| II-2.2.4 | Waters | 113 |
| II-2.2.5 | Air | 114 |
| II-2.2.6 | Plants | 114 |
| II-2.2.7 | Humans | 116 |
| II-2.2.8 | Strontium-90 | 117 |
| II-2.3 | Barium (Ba) | 119 |
| II-2.3.1 | Introduction | 119 |
| II-2.3.2 | Production and Use | 119 |
| II-2.3.3 | Soils | 120 |
| II-2.3.4 | Waters | 120 |
| II-2.3.5 | Air | 121 |
| II-2.3.6 | Plants | 121 |
| II-2.3.7 | Humans | 121 |
| II-2.4 | Radium (Ra) | 123 |
| II-2.4.1 | Introduction | 123 |
| II-2.4.2 | Soils | 124 |
| II-2.4.3 | Waters | 124 |
| II-2.4.4 | Air | 124 |
| II-2.4.5 | Plants | 125 |
| II-2.4.6 | Humans | 125 |

| | | |
|-------------|--|-----|
| II-3 | Trace Elements of Group 3 (Previously Group IIIb) | 127 |
| II-3.1 | Scandium (Sc) | 127 |
| II-3.1.1 | Introduction | 127 |
| II-3.1.2 | Production and Use | 127 |
| II-3.1.3 | Soils | 128 |
| II-3.1.4 | Waters | 128 |
| II-3.1.5 | Air | 129 |
| II-3.1.6 | Plants | 130 |
| II-3.1.7 | Humans | 130 |
| II-3.2 | Yttrium (Y) | 130 |
| II-3.2.1 | Introduction | 130 |
| II-3.2.2 | Production and Use | 131 |
| II-3.2.3 | Soils | 131 |
| II-3.2.4 | Waters | 131 |
| II-3.2.5 | Air | 132 |
| II-3.2.6 | Plants | 132 |
| II-3.2.7 | Humans | 132 |
| II-3.3 | Lanthanides | 133 |
| II-3.3.1 | Introduction | 133 |
| II-3.3.2 | Production and Use | 135 |
| II-3.3.3 | Soils | 136 |
| II-3.3.4 | Waters | 138 |
| II-3.3.5 | Air | 138 |
| II-3.3.6 | Plants | 139 |
| II-3.3.7 | Humans | 141 |
| II-3.4 | Actinides | 141 |
| II-3.4.1 | Introduction | 141 |
| II-3.4.2 | Production and Use | 143 |
| II-3.4.3 | Soils | 144 |
| II-3.4.4 | Waters | 146 |
| II-3.4.5 | Air | 147 |
| II-3.4.6 | Plants | 148 |
| II-3.4.7 | Humans | 149 |
| II-4 | Trace Elements of Group 4 (Previously Group IVb) | 151 |
| II-4.1 | Titanium (Ti) | 151 |
| II-4.1.1 | Introduction | 151 |
| II-4.1.2 | Production and Use | 152 |
| II-4.1.3 | Soils | 153 |
| II-4.1.4 | Waters | 153 |
| II-4.1.5 | Air | 154 |
| II-4.1.6 | Plants | 154 |
| II-4.1.7 | Humans and Animals | 155 |
| II-4.2 | Zirconium (Zr) | 156 |
| II-4.2.1 | Introduction | 156 |
| II-4.2.2 | Production and Use | 156 |

| | | | |
|--------|--|--------------------|-----|
| | II-4.2.3 | Soils | 156 |
| | II-4.2.4 | Waters | 157 |
| | II-4.2.5 | Air | 157 |
| | II-4.2.6 | Plants | 157 |
| | II-4.2.7 | Humans | 158 |
| II-4.3 | Hafnium (Hf) | | 158 |
| | II-4.3.1 | Introduction | 158 |
| | II-4.3.2 | Production and Use | 158 |
| | II-4.3.3 | Soils | 158 |
| | II-4.3.4 | Waters | 159 |
| | II-4.3.5 | Air | 159 |
| | II-4.3.6 | Plants | 159 |
| | II-4.3.7 | Humans | 159 |
| II-5 | Trace Elements of Group 5 (Previously Group Vb) | | 161 |
| II-5.1 | Vanadium (V) | | 161 |
| | II-5.1.1 | Introduction | 161 |
| | II-5.1.2 | Production and Use | 163 |
| | II-5.1.3 | Soils | 163 |
| | II-5.1.4 | Waters | 164 |
| | II-5.1.5 | Air | 165 |
| | II-5.1.6 | Plants | 165 |
| | II-5.1.7 | Humans and Animals | 166 |
| II-5.2 | Niobium (Nb) | | 167 |
| | II-5.2.1 | Introduction | 167 |
| | II-5.2.2 | Production and Use | 168 |
| | II-5.2.3 | Soils | 168 |
| | II-5.2.4 | Waters | 168 |
| | II-5.2.5 | Air | 169 |
| | II-5.2.6 | Plants | 169 |
| | II-5.2.7 | Humans | 169 |
| II-5.3 | Tantalum (Ta) | | 169 |
| | II-5.3.1 | Introduction | 169 |
| | II-5.3.2 | Production and Use | 170 |
| | II-5.3.3 | Soils | 170 |
| | II-5.3.4 | Waters | 170 |
| | II-5.3.5 | Air | 170 |
| | II-5.3.6 | Plants | 171 |
| | II-5.3.7 | Humans | 171 |
| II-6 | Trace Elements of Group 6 (Previously Group VIb) | | 173 |
| II-6.1 | Chromium (Cr) | | 173 |
| | II-6.1.1 | Introduction | 173 |
| | II-6.1.2 | Production and Use | 175 |
| | II-6.1.3 | Soils | 175 |

| | | |
|----------|--|-----|
| II-6.1.4 | Waters | 179 |
| II-6.1.5 | Air | 180 |
| II-6.1.6 | Plants | 181 |
| II-6.1.7 | Humans | 182 |
| II-6.2 | Molybdenum (Mo) | 184 |
| II-6.2.1 | Introduction | 184 |
| II-6.2.2 | Production and Use | 184 |
| II-6.2.3 | Soils | 184 |
| II-6.2.4 | Waters | 185 |
| II-6.2.5 | Air | 186 |
| II-6.2.6 | Plants | 186 |
| II-6.2.7 | Humans and Animals | 188 |
| II-6.3 | Tungsten (W) | 189 |
| II-6.3.1 | Introduction | 189 |
| II-6.3.2 | Production and Use | 189 |
| II-6.3.3 | Soils | 190 |
| II-6.3.4 | Waters | 190 |
| II-6.3.5 | Air | 191 |
| II-6.3.6 | Plants | 191 |
| II-6.3.7 | Humans and Animals | 192 |
| II-7 | Trace Elements of Group 7 (Previously Group VIIb) | 193 |
| II-7.1 | Manganese (Mn) | 193 |
| II-7.1.1 | Introduction | 193 |
| II-7.1.2 | Production and Use | 195 |
| II-7.1.3 | Soils | 195 |
| II-7.1.4 | Waters | 199 |
| II-7.1.5 | Air | 200 |
| II-7.1.6 | Plants | 201 |
| II-7.1.7 | Humans and Animals | 204 |
| II-7.2 | Technetium (Tc) | 206 |
| II-7.2.1 | Introduction | 206 |
| II-7.2.2 | Occurrence in the Environment | 206 |
| II-7.3 | Rhenium (Re) | 207 |
| II-7.3.1 | Introduction | 207 |
| II-7.3.2 | Occurrence in the Environment | 207 |
| II-8 | Trace Elements of Group 8 (Previously Part of Group VIII) | 209 |
| II-8.1 | Iron (Fe) | 209 |
| II-8.1.1 | Introduction | 209 |
| II-8.1.2 | Production and Use | 210 |
| II-8.1.3 | Soils | 211 |
| II-8.1.4 | Waters | 216 |
| II-8.1.5 | Air | 217 |
| II-8.1.6 | Plants | 217 |

| | | |
|--------------|---|------------|
| II-8.1.7 | Humans and Animals | 220 |
| II-8.2 | Ruthenium (Ru) | 222 |
| II-8.2.1 | Introduction | 222 |
| II-8.2.2 | Soils and Plants | 223 |
| II-8.2.3 | Humans | 223 |
| II-8.3 | Osmium (Os) | 224 |
| II-9 | Trace Elements of Group 9 (Previously Part of Group VIII) | 225 |
| II-9.1 | Cobalt (Co) | 225 |
| II-9.1.1 | Introduction | 225 |
| II-9.1.2 | Production and Use | 226 |
| II-9.1.3 | Soils | 227 |
| II-9.1.4 | Waters | 229 |
| II-9.1.5 | Air | 230 |
| II-9.1.6 | Plants | 231 |
| II-9.1.7 | Humans and Animals | 233 |
| II-9.2 | Rhodium (Rh) | 235 |
| II-9.2.1 | Introduction | 235 |
| II-9.2.2 | Occurrence in the Environment | 235 |
| II-9.3 | Iridium (Ir) | 236 |
| II-9.3.1 | Introduction | 236 |
| II-9.3.2 | Occurrence in the Environment | 236 |
| II-10 | Trace Elements of Group 10 (Previously Part of Group VIII) | 237 |
| II-10.1 | Nickel (Ni) | 237 |
| II-10.1.1 | Introduction | 237 |
| II-10.1.2 | Production and Use | 238 |
| II-10.1.3 | Soils | 238 |
| II-10.1.4 | Waters | 241 |
| II-10.1.5 | Air | 243 |
| II-10.1.6 | Plants | 243 |
| II-10.1.7 | Humans and Animals | 247 |
| II-10.2 | Palladium (Pd) | 248 |
| II-10.2.1 | Introduction | 248 |
| II-10.2.2 | Production and Use | 249 |
| II-10.2.3 | Soils | 249 |
| II-10.2.4 | Waters | 249 |
| II-10.2.5 | Air | 250 |
| II-10.2.6 | Plants | 250 |
| II-10.2.7 | Humans | 251 |
| II-10.3 | Platinum (Pt) | 251 |
| II-10.3.1 | Introduction | 251 |
| II-10.3.2 | Production and Use | 252 |
| II-10.3.3 | Soils | 252 |
| II-10.3.4 | Waters | 253 |
| II-10.3.5 | Air | 254 |

| | | |
|--------------|--|------------|
| II-10.3.6 | Plants | 254 |
| II-10.3.7 | Humans | 254 |
| II-11 | Trace Elements of Group 11 (Previously Group Ib) | 257 |
| II-11.1 | Copper (Cu) | 257 |
| II-11.1.1 | Introduction | 257 |
| II-11.1.2 | Production and Use | 259 |
| II-11.1.3 | Soils | 259 |
| II-11.1.4 | Waters | 262 |
| II-11.1.5 | Air | 265 |
| II-11.1.6 | Plants | 266 |
| II-11.1.7 | Humans and Animals | 268 |
| II-11.2 | Silver (Ag) | 271 |
| II-11.2.1 | Introduction | 271 |
| II-11.2.2 | Production and Use | 271 |
| II-11.2.3 | Soils | 272 |
| II-11.2.4 | Waters | 273 |
| II-11.2.5 | Air | 275 |
| II-11.2.6 | Plants | 276 |
| II-11.2.7 | Humans and Animals | 277 |
| II-11.3 | Gold (Au) | 278 |
| II-11.3.1 | Introduction | 278 |
| II-11.3.2 | Production and Use | 278 |
| II-11.3.3 | Soils | 279 |
| II-11.3.4 | Waters | 279 |
| II-11.3.5 | Air | 280 |
| II-11.3.6 | Plants | 280 |
| II-11.3.7 | Humans | 281 |
| II-12 | Trace Elements of Group 12 (Previously Group IIb) | 283 |
| II-12.1 | Zinc (Zn) | 283 |
| II-12.1.1 | Introduction | 283 |
| II-12.1.2 | Production and Use | 285 |
| II-12.1.3 | Soils | 285 |
| II-12.1.4 | Waters | 287 |
| II-12.1.5 | Air | 289 |
| II-12.1.6 | Plants | 289 |
| II-12.1.7 | Humans and Animals | 292 |
| II-12.2 | Cadmium (Cd) | 294 |
| II-12.2.1 | Introduction | 294 |
| II-12.2.2 | Production and Use | 294 |
| II-12.2.3 | Soils | 295 |
| II-12.2.4 | Waters | 299 |
| II-12.2.5 | Air | 302 |
| II-12.2.6 | Plants | 302 |
| II-12.2.7 | Humans and Animals | 305 |

| | | |
|-----------|--|-----|
| II-12.3 | Mercury (Hg) | 308 |
| II-12.3.1 | Introduction | 308 |
| II-12.3.2 | Production and Use | 309 |
| II-12.3.3 | Soils | 310 |
| II-12.3.4 | Waters | 312 |
| II-12.3.5 | Air | 315 |
| II-12.3.6 | Plants | 316 |
| II-12.3.7 | Humans and Animals | 318 |
| II-13 | Trace Elements of Group 13 (Previously Group IIIa) | 321 |
| II-13.1 | Boron (B) | 321 |
| II-13.1.1 | Introduction | 321 |
| II-13.1.2 | Production and Use | 323 |
| II-13.1.3 | Soils | 324 |
| II-13.1.4 | Waters | 325 |
| II-13.1.5 | Air | 327 |
| II-13.1.6 | Plants | 327 |
| II-13.1.7 | Humans | 329 |
| II-13.2 | Aluminum (Al) | 331 |
| II-13.2.1 | Introduction | 331 |
| II-13.2.2 | Production and Use | 331 |
| II-13.2.3 | Soils | 332 |
| II-13.2.4 | Waters | 333 |
| II-13.2.5 | Air | 334 |
| II-13.2.6 | Plants | 335 |
| II-13.2.7 | Humans and Animals | 337 |
| II-13.3 | Gallium (Ga) | 338 |
| II-13.3.1 | Introduction | 338 |
| II-13.3.2 | Production and Use | 339 |
| II-13.3.3 | Soils | 339 |
| II-13.3.4 | Waters | 340 |
| II-13.3.5 | Air | 341 |
| II-13.3.6 | Plants | 341 |
| II-13.3.7 | Humans | 342 |
| II-13.4 | Indium (In) | 342 |
| II-13.4.1 | Introduction | 342 |
| II-13.4.2 | Production and Use | 342 |
| II-13.4.3 | Soils | 343 |
| II-13.4.4 | Waters | 343 |
| II-13.4.5 | Air | 343 |
| II-13.4.6 | Plants | 344 |
| II-13.4.7 | Humans | 344 |
| II-13.5 | Thallium (Tl) | 345 |
| II-13.5.1 | Introduction | 345 |
| II-13.5.2 | Production and Use | 345 |

| | | |
|--------------|--|------------|
| II-13.5.3 | Soils | 346 |
| II-13.5.4 | Waters | 347 |
| II-13.5.5 | Air | 348 |
| II-13.5.6 | Plants | 348 |
| II-13.5.7 | Humans and Animals | 349 |
| II-14 | Trace Elements of Group 14 (Previously Group IVa) | 351 |
| II-14.1 | Silicon (Si) | 351 |
| II-14.1.1 | Introduction | 351 |
| II-14.1.2 | Production and Use | 353 |
| II-14.1.3 | Soils | 353 |
| II-14.1.4 | Waters | 354 |
| II-14.1.5 | Air | 354 |
| II-14.1.6 | Plants | 355 |
| II-14.1.7 | Humans and Animals | 356 |
| II-14.2 | Germanium (Ge) | 357 |
| II-14.2.1 | Introduction | 357 |
| II-14.2.2 | Production and Use | 357 |
| II-14.2.3 | Soils | 358 |
| II-14.2.4 | Waters | 358 |
| II-14.2.5 | Air | 359 |
| II-14.2.6 | Plants | 359 |
| II-14.2.7 | Humans and Animals | 360 |
| II-14.3 | Tin (Sn) | 361 |
| II-14.3.1 | Introduction | 361 |
| II-14.3.2 | Production and Use | 361 |
| II-14.3.3 | Soils | 361 |
| II-14.3.4 | Waters | 362 |
| II-14.3.5 | Air | 366 |
| II-14.3.6 | Plants | 366 |
| II-14.3.7 | Humans | 367 |
| II-14.4 | Lead (Pb) | 368 |
| II-14.4.1 | Introduction | 368 |
| II-14.4.2 | Production and Use | 368 |
| II-14.4.3 | Soils | 369 |
| II-14.4.4 | Waters | 372 |
| II-14.4.5 | Air | 374 |
| II-14.4.6 | Plants | 375 |
| II-14.4.7 | Humans and Animals | 378 |
| II-15 | Trace Elements of Group 15 (Previously Group Va) | 381 |
| II-15.1 | Arsenic (As) | 381 |
| II-15.1.1 | Introduction | 381 |
| II-15.1.2 | Production and Use | 383 |
| II-15.1.3 | Soils | 383 |

| | | |
|--------------|--|------------|
| II-15.1.4 | Waters | 384 |
| II-15.1.5 | Air | 386 |
| II-15.1.6 | Plants | 387 |
| II-15.1.7 | Humans and Animals | 389 |
| II-15.2 | Antimony (Sb) | 391 |
| II-15.2.1 | Introduction | 391 |
| II-15.2.2 | Production and Use | 392 |
| II-15.2.3 | Soils | 392 |
| II-15.2.4 | Waters | 393 |
| II-15.2.5 | Air | 393 |
| II-15.2.6 | Plants | 394 |
| II-15.2.7 | Humans and Animals | 395 |
| II-15.3 | Bismuth (Bi) | 396 |
| II-15.3.1 | Introduction | 396 |
| II-15.3.2 | Production and Use | 396 |
| II-15.3.3 | Soils | 396 |
| II-15.3.4 | Waters | 397 |
| II-15.3.5 | Air | 398 |
| II-15.4.6 | Plants | 398 |
| II-15.4.7 | Humans and Animals | 398 |
| II-16 | Trace Elements of Group 16 (Previously Group VIa) | 401 |
| II-16.1 | Selenium (Se) | 401 |
| II-16.1.1 | Introduction | 401 |
| II-16.1.2 | Production and Use | 403 |
| II-16.1.3 | Soils | 404 |
| II-16.1.4 | Waters | 407 |
| II-16.1.5 | Air | 408 |
| II-16.1.6 | Plants | 409 |
| II-16.1.7 | Humans and Animals | 415 |
| II-16.2 | Tellurium (Te) | 420 |
| II-16.2.1 | Introduction | 420 |
| II-16.2.2 | Production and Use | 421 |
| II-16.2.3 | Soils | 421 |
| II-16.2.4 | Waters | 421 |
| II-16.2.5 | Air | 421 |
| II-16.2.6 | Plants | 422 |
| II-16.2.7 | Humans and Animals | 422 |
| II-16.3 | Polonium (Po) | 423 |
| II-16.3.1 | Introduction | 423 |
| II-16.3.2 | Production and Use | 423 |
| II-16.3.3 | Soils and Plants | 423 |
| II-16.3.4 | Waters | 424 |
| II-16.3.5 | Humans | 424 |

| | | |
|--------------|---|-----|
| II-17 | Trace Elements of Group 17 (Previously Group VIIa) | 425 |
| II-17.1 | Fluorine (F) | 425 |
| II-17.1.1 | Introduction | 425 |
| II-17.1.2 | Production and Use | 427 |
| II-17.1.3 | Soils | 427 |
| II-17.1.4 | Waters | 429 |
| II-17.1.5 | Air | 429 |
| II-17.1.6 | Plants | 430 |
| II-17.1.7 | Humans and Animals | 432 |
| II-17.2 | Chlorine (Cl) | 433 |
| II-17.2.1 | Introduction | 433 |
| II-17.2.2 | Production and Use | 434 |
| II-17.2.3 | Soils | 434 |
| II-17.2.4 | Waters | 435 |
| II-17.2.5 | Air | 435 |
| II-17.2.6 | Plants | 436 |
| II-17.2.7 | Humans and Animals | 437 |
| II-17.3 | Bromine (Br) | 438 |
| II-17.3.1 | Introduction | 438 |
| II-17.3.2 | Production and Use | 438 |
| II-17.3.3 | Soils | 439 |
| II-17.3.4 | Waters | 439 |
| II-17.3.5 | Air | 439 |
| II-17.3.6 | Plants | 440 |
| II-17.3.7 | Humans | 441 |
| II-17.4 | Iodine (I) | 442 |
| II-17.4.1 | Introduction | 442 |
| II-17.4.2 | Production and Use | 442 |
| II-17.4.3 | Soils | 443 |
| II-17.4.4 | Waters | 444 |
| II-17.4.5 | Air | 445 |
| II-17.4.6 | Plants | 445 |
| II-17.4.7 | Humans and Animals | 447 |
| | References | 451 |
| | Index | 519 |