

Contents

Foreword	xi
Michel GRÉGOIRE	
Chapter 1. The Earth's Mantle: Phase Diagrams and Mineralogical Composition	1
Jean-Philippe PERRILLAT	
1.1. Introduction.	1
1.2. Phase relationships: experiments and models.	2
1.2.1. The experimental approach	3
1.2.2. The thermodynamic approach	4
1.3. Minerals in the Earth's mantle.	7
1.3.1. The effects of pressure and temperature on crystal structures	7
1.3.2. The SiO ₂ system.	9
1.3.3. The MgO-FeO-SiO ₂ system.	10
1.3.4. The CaO-MgO-Al ₂ O ₃ - SiO ₂ -FeO (CMASF) system	15
1.4. Phase diagrams of ultrabasic rocks, seismic discontinuities and mantle dynamics	17
1.5. Phase diagram of subducted basalts and fate of plates in the deep mantle	21
1.6. D'' zone and bridgmanite–post-perovskite transition	23
1.7. Conclusion	24
1.8. References	25

Chapter 2. Seismology of the Earth's Mantle	33
Stéphanie DURAND, Benoît TAUZIN and Éric DEBAYLE	
2.1. Introduction.	33
2.2. The architecture of the mantle: seismic discontinuities	39
2.2.1. Seismology with arrays of sensors	39
2.2.2. The mantle transition zone	41
2.2.3. The D'' layer near the core-mantle boundary	47
2.3. The drapery: three-dimensional variations of seismic velocities.	52
2.3.1. Tomographic inversions	52
2.3.2. The lithosphere–asthenosphere system	56
2.3.3. The mid-mantle	58
2.3.4. LLSVPs.	60
2.4. Mantle flow and partial melting: seismic anisotropy and attenuation	61
2.4.1. Azimuthal and radial anisotropy	61
2.4.2. Attenuation in the Earth's mantle	63
2.5. References	68
Chapter 3. The Deep Hydrogen Cycle	83
Nathalie BOLFAN-CASANOVA and Bertrand MOINE	
3.1. Introduction.	83
3.2. The origin of terrestrial water	84
3.2.1. The message of meteorites	84
3.2.2. The age of the oceans: the rock record	87
3.3. Water distribution in the various onshore reservoirs.	87
3.3.1. Surface reservoirs	87
3.3.2. Deep Earth reservoirs	87
3.3.3. Water storage capacity in the mantle	100
3.3.4. The effect of water on mantle melting.	100
3.3.5. Water transfers between reservoirs.	101
3.4. Hydrothermal weathering on the ocean floor	101
3.4.1. Subduction and dehydration of the subducted plate	103
3.4.2. Hydrogen speciation	106
3.5. References	107

Chapter 4. The Role of Volatile CO₂-H₂O Species in the Melting of the Earth's Mantle	115
Malcolm MASSUYEAU and Tahar HAMMOUDA	
4.1. Presence and storage of carbon and hydrogen in the upper mantle . . .	116
4.2. Effects of CO ₂ and H ₂ O on melting temperatures in the Earth's peridotitic mantle	118
4.2.1. H ₂ O partitioning between magmatic liquid and silicate minerals, and mantle melting in the presence of water	118
4.2.2. Low carbonate melting temperatures	123
4.2.3. Simultaneous presence of CO ₂ and H ₂ O in the peridotitic mantle	124
4.3. Composition of mantle magmas in the presence of CO ₂ and H ₂ O. . . .	125
4.3.1. Composition of magmatic liquids as a function of P-T-X conditions	126
4.3.2. Composition and fraction of magmatic liquid produced in the mantle.	128
4.4. Impact of CO ₂ and H ₂ O on the mantle's geophysical signatures	133
4.5. References	135
Chapter 5. Oxygen Fugacity in the Mantle	147
Alan B. WOODLAND	
5.1. Introduction.	147
5.2. Equilibria with iron oxides.	147
5.3. The significance of oxygen fugacity	151
5.4. The f_{O_2} importance for processes in the Earth's interior	154
5.4.1. The stability of ferriferous minerals	154
5.4.2. The stability of carbon-bearing phases	155
5.4.3. The possibility of a metallic phase	156
5.4.4. Trace element behavior	157
5.4.5. C-O-H fluid composition and redox melting	159
5.4.6. Partial melting conditions in the upper mantle	162
5.5. Determining the f_{O_2} content of a rock.	164
5.6. The f_{O_2} of the upper mantle (lithospheric)	169
5.6.1. Oceanic ridges	169
5.6.2. Subduction zones	171
5.6.3. The subcontinental lithospheric mantle	173
5.6.4. Orogenic massifs	174

5.6.5. The cratonic lithosphere	175
5.6.6. The message from eclogites	176
5.7. Redox conditions in the deep mantle	178
5.8. A final word	181
5.9. References	182
Chapter 6. Elasticity and Composition of the Earth's Mantle	193
Tiziana BOFFA-BALLARAN	
6.1. Elasticity	194
6.1.1. The effect of crystal symmetry on the elasticity	197
6.1.2. A special state of stress: hydrostatic pressure	198
6.1.3. Reuss and Voigt bounds	201
6.1.4. Isothermal and adiabatic moduli	202
6.2. Elastic waves	203
6.3. Polycrystalline materials	206
6.4. Experimental techniques	208
6.4.1. Instruments for generating high pressure and high temperature	208
6.4.2. Static compression experiments	209
6.4.3. Ultrasonic methods	210
6.4.4. Light scattering techniques	211
6.5. Models of the Earth's interior	212
6.6. References	216
Chapter 7. Earth's Mantle Rheology	221
Sylvie DEMOUCHEY and Patrick CORDIER	
7.1. Introduction.	221
7.2. Ductile deformation: mechanisms	223
7.2.1. Point defects	223
7.2.2. Line defects: dislocations	226
7.2.3. Grain boundaries	229
7.3. Observables.	231
7.4. Methodological approaches	233
7.4.1. Field.	233
7.4.2. Laboratory-based experiments	234
7.4.3. Looking at the deformation through a microscope	236
7.4.4. Multiscale numerical modelling	236

7.5. Deformation in the upper mantle	237
7.6. Deformation in the mantle transition zone.	240
7.7. Deformation in the lower mantle	242
7.8. Conclusion	244
7.9. References	245

Chapter 8. Laboratory Measurements of Electrical Conductivity and their Applications to Planetary Interiors 249

Geeth MANTHILAKE

8.1. Theoretical background.	249
8.2. Laboratory measurements of electrical conductivity.	251
8.2.1. Two-terminal method	251
8.2.2. Four-terminal method	251
8.2.3. Impedance spectroscopy technique	252
8.2.4 Electrical conductivity measurements at high pressure and high temperature.	254
8.3. Laboratory measurements of electrical conductivity.	255
8.3.1. Ionic conduction.	256
8.3.2. Hopping (small polaron) conduction.	257
8.3.3. Proton conduction.	257
8.4. Electrical conductivity of a composite medium	257
8.5. Factors affecting the electrical conductivity of planetary materials	258
8.5.1. Effect of pressure and temperature.	259
8.5.2. Effect of chemistry	260
8.5.3. Effect of oxygen fugacity	261
8.5.4. Influence of crystallographic orientation of minerals	262
8.5.5. Influence of grain boundaries	262
8.5.6. Effects of dehydration and fluid release.	263
8.5.7. Effects of melting	264
8.6. The modeling of electrical conductivity data for planetary applications	265
8.6.1. To detect chemical heterogeneities in the mantle	266
8.6.2. Electrical conductivity as a geothermometer	267
8.6.3. As a tool to constrain water content in the mantle.	269
8.6.4. Applications to melting in planetary interiors	270
8.6.5. Fluid circulation in subduction zones	271
8.6.6. Electrical conductivity in metals: applications to thermal transporting properties	272
8.6. References	273

List of Authors	279
Index	281