Contents

Foreword xi
Claude JAUPART

Preface xv
Jean-François LÉNAT

List of Abbreviations xvii

Chapter 1. Seismic Monitoring of Volcanoes and Eruption Forecasting 1
Philippe LESAGE

1.1. Introduction. 1
1.2. Instrumentation and seismic networks 2
1.2.1. Measurement systems 2
1.2.2. Sensors 3
1.2.3. Monitoring network 5
1.3. Types of seismic-volcanic events 10
1.3.1. Introduction 10
1.3.2. Volcano-tectonic earthquakes (VT, A-type, high-frequency, HF) 11
1.3.3. Long-period earthquakes (LP, B-type, low-frequency, LF) 12
1.3.4. Hybrid earthquakes (C-type, multiphase, MP) 14
1.3.5. Explosions 15

1.3.6. Very-long-period (VLP or VLF) and ultra-long-period (ULP) events 16
1.3.7. Volcanic tremor 17
1.3.8. Surficial phenomena 19
1.3.9. Distortions in seismic signals 20
1.4. Volcanic seismicity 20
1.4.1. Main characteristics 21
1.4.2. Pre-eruptive seismic activity, precursors 24
1.4.3. Generic models of seismic-volcanic swarms and pre-eruptive seismicity 25
1.5. Processing of seismic-volcanic signals 30
1.5.1. Introduction 30
1.5.2. Seismograms 31
1.5.3. Event detection 32
1.5.4. RSAM, RSEM, SSAM 32
1.5.5. Spectral analysis 33
1.5.6. Polarization 35
1.5.7. Correlation 36
1.5.8. Determination of the Base Level Noise Seismic Spectrum 37
1.5.9. Automatic classification 37
1.6. Network data analysis 39
1.6.1. Determination of velocity models 40
1.6.2. Location of seismic sources 40
1.6.3. Seismic moment tensor inversion 46
1.6.4. Array analysis 47
1.6.5. Coda wave interferometry 49
1.7. Forecasting eruptions 55
1.7.1. Introduction 55
1.7.2. Probabilistic forecasting 56
1.7.3. Short-term forecasting 57
1.8. The FFM method 58
1.8.1. Alert systems and volcanic crisis management 60
1.9. Case studies 62
1.9.1. Introduction 62
1.9.2. Kelud volcano, Java, Indonesia 63
1.9.3. The “centennial” eruption of Merapi volcano, 2010 67
1.9.4. Piton de la Fournaise 72
1.9.5. Phreatic eruptions 75
1.9.6. Discussion 76
1.10. Conclusion 77
1.11. References 78

Chapter 2. Monitoring Volcano Deformation 95
Valérie CAYOL, Aline PELTIER, Jean-Luc FROGER and François BEAUDUCEL

2.1. Introduction. 95
2.2. Phenomena at the origin of deformation 97
2.2.1. Deformation related to the inflation-deflation of magmatic reservoirs. 97
2.2.2. Deformation related to magma ascent inside the conduits 101
2.2.3. Deformation of hydrothermal origin 104
2.2.4. Flank destabilization related to endogenous growth. 106
2.2.5. Other sources of deformation 107
2.3. Deformation measurement techniques 107
2.3.1. Leveling measurements 108
2.3.2. Tilt measurements 109
2.3.3. Extensometry 112
2.3.4. Electronic Distance Measurement, trilateration 113
2.3.5. Volumetric strainmeters 114
2.3.6. Satellite positioning system, GNSS 115
2.3.7. InSAR. 116
2.3.8. Stereophotogrammetry 125
2.3.9. Measurements at sea 126
2.4. Adequacy between deformation measurements and monitoring 126
2.5. Contributions and limitations of deformation modeling to the study of volcanoes 130
2.5.1. Reservoir models 131
2.5.2. Conduit models 144
2.5.3. Models without a priori assumptions on source shape 149
2.6. Perspectives: from operational monitoring to physical and predictive models 151
2.7. References 153

Chapter 3. Volcano Monitoring by Remote Sensing 167
Mathieu GOUHIER

3.1. Introduction. 167
3.2. Basic concepts in remote sensing 168
3.2.1. Passive and active sensors. 169
3.2.2. Geostationary and Low Earth Orbit platforms 170
3.2.3. Electromagnetic spectrum 172
3.2.4. Terrestrial infrared radiation 175

3.2.5. Spectral resolution 176
3.3. Main available operating systems 177
3.4. Monitoring volcanic ash plumes 181
3.4.1. Methodology 182
3.4.2. List of main available sensors 186
3.4.3. Case studies: Etna and Eyjafjallajökull 187
3.5. Monitoring volcanic SO_2 plumes 190
3.5.1. Methodology 190
3.5.2. Operational issues 193
3.5.3. Case studies: Holuhraun/Bárðarbunga 195
3.6. Lava flow monitoring 196
3.6.1. Introduction 196
3.6.2. Methodology 197
3.6.3. Case studies: Piton de la Fournaise, 2015 204
3.7. Future developments 206
3.8. References 207

Chapter 4. Volcano Remote Sensing with Ground-Based Techniques 211
Franck DONNADIEU, David JESSOP, Philipson BANI and Séverine MOUNE

4.1. Introduction 211
4.2. Basic concepts in ground-based remote sensing relying on electromagnetic waves 212
4.2.1. Electromagnetic spectrum 212
4.2.2. Propagation of electromagnetic waves 213
4.2.3. Scattering and absorption 213
4.3. Ground remote sensing for the detection of volcanic gas 215
4.3.1. Introduction 215
4.3.2. Why become interested in volcanic degassing? 216
4.3.3. Measurement methods 220
4.3.4. Future developments 235
4.3.5. Conclusion 236
4.4. Ground-based IR remote sensing 237
4.4.1. History and development of ground-based thermal remote sensing instruments 238
4.4.2. Examples of thermal cameras used in volcanology 240
4.4.3. Physical principles 243
4.4.4. Characteristics and practical considerations for using thermal imaging instruments 246

4.5. Other volcano remote sensing methods with ground-based techniques 253
4.5.1. Introduction 253
4.5.2. The importance of monitoring ash plumes 253
4.5.3. Radars, operational tools. 254
4.5.4. Monitoring proximal ash fallout: disdrometers 264
4.5.5. Monitoring of volcanic storms 268
4.5.6. Atmospheric lidars to probe low concentration ash clouds. 274
4.5.7. Plume detection by GNSS networks 277
4.5.8. Monitoring topographic changes 278
4.5.9. Monitoring underwater volcanic activity by means of acoustic methods 285
4.6. Future developments 288
4.7. References 289

List of Authors 303

Index 305