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H. JAY MELOSH is Distinguished Professor of Earth and Atmospheric Science at Purdue University. His principal research interests are impact cratering, planetary tectonics, and the physics of earthquakes and landslides. He is a science team member of NASA's Deep Impact mission that successfully cratered comet Tempel 1 on July 4, 2005. Professor Melosh was awarded the Barringer Medal of the Meteoritical Society in 1999, the Gilbert prize of the Geological Society of America in 2001, the Hess Medal of the American Geophysical Union in 2008, and was elected to the US National Academy of Sciences in 2003. He has published over 170 technical papers, edited two books and is the author of *Impact Cratering: A Geologic Process* (1989, Oxford University Press). Asteroid #8216 was named "Melosh" in his honor.

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H. JAY MELOSH

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This book is dedicated to the students and colleagues who participated in my class PtyS 554, Planetary Surfaces, and PtyS 594, Planetary Field Geology Practicum, at the Lunar and Planetary Lab of the University of Arizona and at Caltech and Stony Brook before that. In the years stretching from 1976 to 2009 and from the classroom to campfires in unearthly landscapes under star-studded skies, we all learned together.

Contents

Preface	*page* xv
Acknowledgments	xix
1 The grand tour	1
1.1 Structure of the Solar System	2
1.1.1 Major facts of the Solar System	3
1.1.2 Varieties of objects in the Solar System	4
1.2 Classification of the planets	5
1.2.1 Retention of planetary atmospheres	6
1.2.2 Geologic processes on the terrestrial planets and moons	7
1.3 Planetary surfaces and history	9
1.3.1 The Moon	10
1.3.2 Mercury	14
1.3.3 Venus	15
1.3.4 Mars	16
1.3.5 Jupiter's Galilean satellites	18
1.3.6 Titan	20
1.3.7 The Earth	22
Further reading	24
2 The shapes of planets and moons	25
2.1 The overall shapes of planets	26
2.1.1 Non-rotating planets: spheres	26
2.1.2 Rotating planets: oblate spheroids	27
2.1.3 Tidally deformed bodies: triaxial ellipsoids	30
2.1.4 A scaling law for planetary figures?	34
2.1.5 Center of mass to center of figure offsets	34
2.1.6 Tumbling moons and planets	35
2.2 Higher-order topography: continents and mountains	36
2.2.1 How high is high?	36
2.2.2 Elevation statistics: hypsometric curves	38
Box 2.1 Topographic roughness	40

2.2.3 Where are we? Latitude and longitude on the planets 41
2.3 Spectral representation of topography 44
Further reading 47
Exercises 47

3 Strength versus gravity 49
3.1 Topography and stress 49
Box 3.1 Collapse of topography on a strengthless planet 51
3.2 Stress and strain: a primer 52
3.2.1 Strain 52
3.2.2 Stress 53
3.2.3 Stress and strain combined: Hooke's law 55
3.2.4 Stress, strain, and time: viscosity 57
3.3 Linking stress and strain: Jeffreys' theorem 58
3.3.1 Elastic deformation and topographic support 58
3.3.2 Elastic stress solutions and a limit theorem 60
3.3.3 A model of planetary topography 62
3.4 The nature of strength 64
3.4.1 Rheology: elastic, viscous, plastic, and more 64
3.4.2 Long-term strength 64
Box 3.2 The ultimate strength of solids 65
3.4.3 Creep: strength cannot endure 74
3.4.4 Planetary strength profiles 80
3.5 Mechanisms of topographic support 82
3.5.1 Plastic strength: Jeffreys' limit again 82
3.5.2 Viscous relaxation of topography 82
3.5.3 The topographic advantages of density differences: isostatic support 87
3.5.4 Dynamic topography 90
3.5.5 Floating elastic shells: flexural support of topographic loads 91
3.6 Clues to topographic support 93
Box 3.3 Flexure of a floating elastic layer 94
3.6.1 Flexural profiles 96
3.6.2 Anomalies in the acceleration of gravity 97
3.6.3 Geoid anomalies 99
Box 3.4 The ambiguous lithosphere 100
Further reading 100
Exercises 101

4 Tectonics 104
4.1 What is tectonic deformation? 104
4.1.1 Rheologic structure of planets 105
4.1.2 One- and multiple-plate planets 107

4.2 Sources of tectonic stress 108
4.2.1 External sources of tectonic stress 108
4.2.2 Internal sources of tectonic stress 109
4.3 Planetary engines: heat sources and heat transfer 113
4.3.1 Accretional heat 113
4.3.2 Tidal dissipation in planetary interiors 114
4.3.3 Heat transfer by thermal conduction and radiogenic heat production 116
4.3.4 Thermal convection and planetary heat transfer 121
4.4 Rates of tectonic deformation 127
4.5 Flexures and folds 128
4.5.1 Compression: folding of rocks 128
Box 4.1 Elastic and viscous buckling theory 130
4.5.2 Folding vs. faulting: fault-bend folds 133
4.5.3 Extension: boudinage or necking instability 135
4.5.4 Gravitational instability: diapirs and intrusions 136
4.6 Fractures and faults 139
4.6.1 Why faults? Localization 139
4.6.2 Joints, joint networks, and lineaments 141
4.6.3 Faults: Anderson's theory of faulting 143
Box 4.2 Dip angle of Anderson faults 147
4.7 Tectonic associations 154
4.7.1 Planetary grid systems 154
4.7.2 Flexural domes and basins 155
4.7.3 Stress interactions: refraction of grabens by loads 157
4.7.4 Io's sinking lithosphere 158
4.7.5 Terrestrial plate tectonics 160
Further reading 161
Exercises 162

5 Volcanism 169
5.1 Melting and magmatism 169
5.1.1 Why is planetary volcanism so common? 170
Box 5.1 The adiabatic gradient 173
5.1.2 Melting real planets 175
5.1.3 Physical properties of magma 183
5.1.4 Segregation and ascent of magma 187
Box 5.2 The standpipe model of magma ascent 189
5.2 Mechanics of eruption and volcanic constructs 194
5.2.1 Central versus fissure eruptions 194
5.2.2 Physics of quiescent versus explosive eruptions 195
Box 5.3 A speed limit for volcanic ejecta 200

	5.2.3 Volcanic surface features	204
5.3	Lava flows, domes, and plateaus	208
	5.3.1 Lava flow morphology	208
	5.3.2 The mechanics of lava flows	210
	5.3.3 Lava domes, channels, and plateaus	214
	Further reading	218
	Exercises	218
6	Impact cratering	222
6.1	History of impact crater studies	222
6.2	Impact crater morphology	223
	6.2.1 Simple craters	224
	6.2.2 Complex craters	224
	6.2.3 Multiring basins	226
	6.2.4 Aberrant crater types	228
	6.2.5 Degraded crater morphology	229
6.3	Cratering mechanics	229
	6.3.1 Contact and compression	230
	6.3.2 Excavation	233
	6.3.3 Modification	238
	Box 6.1 Maxwell's Z model of crater excavation	242
6.4	Ejecta deposits	244
	6.4.1 Ballistic sedimentation	246
	6.4.2 Fluidized ejecta blankets	248
	6.4.3 Secondary craters	250
	6.4.4 Oblique impact	251
6.5	Scaling of crater dimensions	251
	6.5.1 Crater diameter scaling	252
	6.5.2 Impact melt mass	253
6.6	Atmospheric interactions	254
6.7	Cratered landscapes	255
	6.7.1 Description of crater populations	256
	6.7.2 Evolution of crater populations	261
6.8	Dating planetary surfaces with impact craters	262
	6.8.1 $b > 2$ population evolution	263
	6.8.2 $b < 2$ population evolution	265
	6.8.3 Leading/trailing asymmetry	266
6.9	Impact cratering and planetary evolution	267
	6.9.1 Planetary accretion	267
	6.9.2 Impact catastrophism	268
	6.9.3 Origin of the Moon	269
	6.9.4 Late Heavy Bombardment	269

6.9.5 Impact-induced volcanism? 270
6.9.6 Biological extinctions 271
Further reading 271
Exercises 272

7 Regoliths, weathering, and surface texture 276
7.1 Lunar and asteroid regoliths: soil on airless bodies 276
7.1.1 Impact comminution and gardening 279
Box 7.1 Growth of the lunar regolith 282
7.1.2 Regolith maturity 285
7.1.3 Radiation effects on airless bodies 286
7.2 Temperatures beneath planetary surfaces 288
7.2.1 Diurnal and seasonal temperature cycles 289
7.2.2 Heat transfer in regoliths 290
7.2.3 Thermal inertia 293
7.3 Weathering: processes at the surface/atmosphere interface 293
7.3.1 Chemical weathering 295
7.3.2 Physical weathering 300
7.3.3 Sublimation weathering 306
7.3.4 Duricrusts and cavernous weathering 308
7.3.5 Desert varnish 309
7.3.6 Terrestrial soils 310
7.4 Surface textures 311
7.4.1 "Fairy castle" lunar surface structure 311
7.4.2 Stone pavements: why the Brazil nuts are on top 313
7.4.3 Mudcracks, desiccation features 315
Further reading 316
Exercises 316

8 Slopes and mass movement 319
8.1 Soil creep 319
8.1.1 Mechanism of soil creep 320
8.1.2 Landforms of creeping terrain 323
8.2 Landslides 326
8.2.1 Loose debris: cohesion $c = 0$ 327
8.2.2 Cohesive materials $c > 0$ 331
Box 8.1 Crater terraces as slump blocks 336
8.2.3 Gravity currents 339
8.2.4 Long-runout landslides or *sturzstroms* 340
Further reading 344
Exercises 345

9 Wind	348
9.1 Sand vs. dust	349
9.1.1 Terminal velocity	349
9.1.2 Suspension of small particles	352
9.2 Motion of sand-sized grains	353
9.2.1 Initiation of motion	354
9.2.2 Transport by the wind	361
9.2.3 The entrainment of dust	363
9.2.4 Abrasion by moving sand	365
9.3 Eolian landforms	365
9.3.1 The instability of sandy surfaces	365
9.3.2 Ripples, ridges, and sand shadows	366
Box 9.1 Kamikaze grains on Mars	368
9.3.3 Dunes	371
9.3.4 Yardangs and deflation	376
9.3.5 Wind streaks	377
9.3.6 Transient phenomena	378
Further reading	379
Exercises	380
10 Water	382
10.1 “Hydrologic” cycles	383
10.1.1 Time, flow, and chance	383
10.1.2 Rainfall: infiltration and runoff	386
10.2 Water below the surface	388
10.2.1 The water table: the piezometric surface	388
10.2.2 Percolation flow	390
10.2.3 Springs and sapping	392
Box 10.1 How long can streams flow after the rain stops?	393
10.3 Water on the surface	395
10.3.1 Overland flow	396
10.3.2 Streamflow	401
10.3.3 Channels	407
Box 10.2 Analysis of stream networks	416
10.3.4 Standing water: oceans, lakes, playas	418
10.3.5 Fluvial landscapes	428
Further reading	431
Exercises	432
11 Ice	434
11.1 Ice on planetary surfaces	434
11.1.1 Ice within the hydrologic cycle	435
11.1.2 Glacier classification	436
11.1.3 Rock glaciers	438

11.2 Flow of glaciers 439
11.2.1 Glen's law 440
11.2.2 The plastic-flow approximation 442
11.2.3 Other ices, other rheologies 443
11.2.4 Basal sliding 444
Box 11.1 Salt glaciers and solution creep 445
11.3 Glacier morphology 446
11.3.1 Flow velocities in glaciers and ice sheets 447
11.3.2 Longitudinal flow regime and crevasses 448
11.3.3 Ice-sheet elevation profile 449
11.4 Glacial landforms 451
11.4.1 Glacial erosion 451
11.4.2 Glacial deposition 452
11.5 Ice in the ground 454
11.5.1 Permafrost 455
11.5.2 Patterned ground 459
11.5.3 Thermokarst 462
Further reading 462
Exercises 463

References 465
Index 485
Color plates appear between pages 236 and 237

Preface

We are privileged to be living in one of the greatest eras of exploration that humankind has ever undertaken. Our current Age of Space grew out of the dark struggles of World War II when large rockets were developed as agents of mass murder. The subsequent Cold War rivalry between the United States and Soviet Union pushed rocket capabilities to the point that it became possible to send vehicles into Earth orbit and beyond (even though the stated aim was to send missiles carrying nuclear weapons over mere continental distances). The Russians put the first human into Earth orbit. The Apollo missions took American astronauts to the Moon, a target that Russia reached first with its unmanned vehicles: Russia stopped just short of a manned lunar landing. Somehow, amid all this politically motivated grandstanding, a few visionary engineers and scientists accomplished the feat that will be remembered by all future generations: the exploration of our Solar System.

While humans have not yet traveled beyond the Moon, robotic spacecraft with increasingly sophisticated electronic brains and sensory systems have now left the bounds of the Solar System. Spacecraft have visited all of the major planets, with the exception of Pluto (although some now argue that it is not really a "major planet"). Many planets and even asteroids have been flown by, orbited and landed upon by spacecraft. We have yet to bring back samples of any body other than the Moon, comet Wild 2 and asteroid 25143 Itokawa, so there is much more to accomplish, but we are learning about the universe outside our little Earth at a tremendous rate.

When I first started teaching a course in Planetary Sciences in 1977 it was possible to treat each individual planet as a separate entity. Weeks would be spent talking about the Moon and its special attributes. Mars was a Moon-like disappointment after the flybys of Mariners 4, 6, and 7 that all, ironically, imaged nothing but the heavily cratered terrains of the southern highlands. Mariner 10 had just returned our first views of Mercury, which also turned out to be very much like the Moon. As time went on, we learned much more about the planets we had first studied and learned new things about planets that had never before been visited by spacecraft. Mars blossomed into a new world in the wake of the Mariner 9 orbiter, with giant volcanoes, canyons that dwarfed Arizona's Grand Canyon and channels that could only have been cut by gigantic floods. Pioneer Venus and the Soviet Veneras made it clear that our "sister" planet was a very odd relative indeed, and the Voyagers were off on their historic tours of the outer Solar System.

Before long it was clear that a planet-by-planet course organization could no longer work. It would be tediously repetitious to talk about craters and volcanoes on the Moon, then later to talk about craters and volcanoes on Mars, and then craters and volcanoes on Mercury, adding a new "craters and volcanoes" block for each new planet. While the number of planets kept multiplying, the number of different geologic processes did not. Pretty much the same processes, modified a bit for local conditions, act on every body we have investigated so far. So the modern course organization emphasizes processes, not individual planets. Furthermore, the body of information about each planet has multiplied to the point that it is no longer possible to comprehensively cover all that is known about even *one* planet within the confines of a one-semester class. If you doubt this, go to a library and look at the shelf of books about planets in just the University of Arizona's Space Science Series. The total collection occupies about two meters of shelf space, and it grows by a few tens of centimeters (or more!) every year.

This practical limitation accounts for the "process" orientation of this book. Beyond this, I had to make decisions about which processes to treat and in what order. Textbooks on terrestrial geomorphology abound and "process orientation" is a buzzword that most modern books respect, but fluvial processes dominate terrestrial geomorphology. Fluvial processes, however, are rare in the larger Universe and must take a back seat to more universal processes, such as impact cratering, in a planetary context. In teaching this class I have long used an approach that follows the planetary exploration mantra of "first flyby, then orbit, land, and finally return samples." I start with those aspects of a planet that you can see from the greatest distance, even telescopically (a level that we have just attained for extrasolar planets). Thus, we can ask: what determines a planet's shape and the topography of its surface? Deviations from a spheroidal shape must be supported by internal strength, which motivates a discussion of what strength is and how topographic variations can be supported.

If topography is limited by strength, then what happens when it is exceeded? The answer is tectonics: faults and fractures. As we approach ever closer to a planet, the next things we might notice are craters, just as the first features on Mars and Mercury imaged by spacecraft were cratered terrains. I had thus planned to make impact craters the subject of Chapter 5, followed by volcanism in Chapter 6. However, one of the anonymous reviewers of my original book proposal cogently argued that volcanism is most closely linked to tectonics so that the order of these two chapters should logically be reversed. I agree, and so the order is as you now have it – after all, the first things that Mariner 9 saw looming out of the global dust storm were the summits of Mars' four great shield volcanoes. The last five chapters are organized around the principle of most-to-least universal processes. All bodies have regoliths, although the regolith of airless bodies such as the Moon or asteroids differs profoundly from the agricultural soil of Earth. Regoliths do not need slopes to form, but mass movement is a process that acts only on slopes, so that is the subject of Chapter 8. Chapters 9, 10, and 11 are, in the broadest sense, about the processes that involve wind, water, and ice, even though the "wind" may be blowing carbon dioxide, the "water" liquid methane, and the "ice" solid carbon dioxide or methane. These chapters are really about transport by atmospheric gases (universal for large enough planets and moons), liquids (fewer bodies possess flowing liquids on their surfaces), and solids warm enough to flow at measurable rates (that is, very close to their melting points, which must be pretty unusual on a planet's surface).

In teaching this course I try to get through the entire set of processes in one semester (15 weeks of three hours of lecture per week). As my former students well know, I often do not succeed. New discoveries come up, someone asks a lot of deep questions about some topic, and I end up spending more time on one topic than the syllabus allows. The result is that I usually have to rush through the last sections. I have often said, "If only there were a text for this course, I could have the students read up on this topic and not miss out on an important idea." Well, here is the text. Maybe it will solve this problem.

Another note about how I teach this class: I typically assign challenging homework problems that are meant to encourage the students to think. There are sometimes no strictly right or wrong answers, just reasonable ones that admit of a lot of interpretation (there are also some easy problems that just involve substitutions, but I hope the answers are enlightening). I also ask the students to write a research paper on some topic that interests them, and I base much of the final grade on these research papers. These papers are about ten pages long and I encourage the students to think independently, not just regurgitate what they may have read in some published paper. New calculations or even small-scale experiments and field investigations are strongly encouraged. I do not penalize the students, gradewise, if some initially promising line of research does not work out. Many of these papers have turned into abstracts presented at the annual *Lunar and Planetary Research Conference*. Some have turned into papers published in the scientific journals and a few have become Ph.D. theses.

Because paper-writing becomes more intense as the semester proceeds, I ease off on the amount of homework assigned to allow the students time to explore their own ideas. This has often resulted in surprising bursts of creative activity that I do not wish to smother under too much "set work." For that reason you will find that the number and difficulty of the exercises associated with each chapter falls off toward the end of the book. I do this in the hope that the early part of the course will serve as a kind of "launch pad" for independent investigation of this fascinating field.

Anyone who teaches this subject must realize that planetary science is an active and ever-changing subject. New discoveries are constantly being made. I have tried to incorporate some of the latest discoveries in this text, but I fully realize that by the time this book appears in print some things I have written will be obsolete (indeed, in my own research I am doing my best to make that happen). So it is important to supplement this text with readings from the current literature and even news stories and NASA data releases.

Ah yes, one last piece of advice (and my former students would not forgive me if I failed to mention this!): The stories. Some of them are here in the book, cleaned up a bit and properly referenced. Not all of them (some of the good ones I was unable to verify in this way – they are in a file labeled "dubious stories" until I can find a reliable reference). Stories about people, about ideas, about what motivated whom to do what and how some great idea came from something that seemed wholly unrelated. Some of it is the usual scuttlebutt of science, told over coffee or around campfires. But most of my stories are different: Like Aesop's fables, they all have a moral. Like all teachers, I am often distressed by how little students seem to remember about some topic after the lapse of even one semester, let alone a few years. So I try to wrap the really important ideas into a really good story about someone or something. I think that makes the idea easier to remember and hope that the idea might remain mentally accessible long after the equation or intricate train of reasoning has passed beyond recall. I am not sure this works, but I do meet students who, after many years, still retain the story, if not the point that it was meant to illustrate. Not everyone who teaches this course will want to emulate this particular technique, but I do ask you not to drain the human interest from the science. Science is done by humans, and for humans to continue to do it they must realize how quirky and illogical the course of discovery can be.

With that, I invite you to move on into this book and make your own discoveries. I hope you have as much fun learning this stuff as I have had.

October 2010
West Lafayette, Indiana

Acknowledgments

I am grateful, most of all, to the many students who participated in my classes and whose questions, answers to homework problems, responses to challenges, insightful research projects, and field trip presentations added immeasurably to my appreciation and knowledge of the surfaces of the various strange objects that inhabit our Solar System. Most of this work, particularly the field component of my classes, would have been impossible without the support of the Department of Planetary Sciences and the Lunar and Planetary Lab of the University of Arizona. There were some tense moments and challenging situations that developed in the field, but overall this support has been exemplary. I had long dreamed of distilling my class lectures into a book, while adding more material that I never had time to cover in a semester course, but it was Susan Francis, of Cambridge University Press, who finally persuaded me to take on this monumental task. The actual writing of this book has stretched over more years than I like to remember, during which time I received aid from a large number of people. Virgina Pasek drafted nearly all of the figures from my rough sketches. Her artistic ability and sense of graphic design shines through in every chapter, except 1 and 6. She has been a steady and patient collaborator and I am most grateful that she agreed to join me in this effort and persisted up to the last moment. As the book neared completion, Francis Nimmo read Chapters 3 and 4 and made numerous helpful suggestions that clarified the accuracy and precision of the material. Several former students contributed figures, particularly Jason Barnes, Eric Palmer, Ralph Lorenz, and Ingrid Daubar-Spitale. Steve Squyres contributed the beautiful cover image of Duck Bay, Mars, through several iterations of re-processing. I am also most grateful to my wife, Ellen Germann-Melosh, who has borne my preoccupation with writing on too many nights and weekends with patience and understanding. She is surely tired of hearing about "The Book" and I am delighted to finally send it forth to whatever fate awaits it in the larger world of science.