

## Contents

Preface to the first edition	<i>page</i> xi
Preface to the second edition	xiii
Physical constants relevant to ice	xiv
Derived SI units and conversion factors	xvii
<b>1 Why study glaciers?</b>	<b>1</b>
<b>2 Some basic concepts</b>	<b>5</b>
A note on units and coordinate axes	5
Glacier size, shape, and temperature	6
The condition of incompressibility	9
Stresses, strains, and strain rates	10
<b>3 Mass balance</b>	<b>17</b>
The transformation of snow to ice	18
Snow stratigraphy	20
Mass balance principles	23
Climatic causes of mass balance fluctuations	26
The budget gradient	29
Other modes of ice loss from valley glaciers	31
Mass balance of polar ice sheets	34
Effect of atmospheric circulation patterns on mass balance	37
Global mass balance	40
Summary	41
<b>4 Flow and fracture of a crystalline material</b>	<b>43</b>
Crystal structure of ice	43
Dislocations	44
Rate-limiting processes	48
Internal stresses	53
Recrystallization	54
Deformation mechanism maps	63
	vii

## viii Contents

	A flow law for glacier ice	66
	Fracture	70
	Summary	74
<b>5</b>	<b>The velocity field in a glacier</b>	<b>76</b>
	Measurement of velocity	77
	Balance velocity	78
	Shear stress distribution	79
	Horizontal velocity at depth in an ice sheet	81
	Horizontal velocity in a valley glacier	83
	Mean horizontal velocity and ice flux	87
	Vertical velocity	88
	Submergence and emergence velocities	91
	Flow field	92
	Transverse profiles of surface elevation on a valley glacier	94
	Radar stratigraphy	96
	Effect of drifting snow on the velocity field	98
	Ice streams	105
	Summary	110
<b>6</b>	<b>Temperature distribution in polar ice sheets</b>	<b>112</b>
	Energy balance in an ice sheet	112
	Dependence of $K$ on temperature	117
	The steady-state temperature profile at the center of an ice sheet	117
	Temperature profiles in the ablation zone	127
	Temperature profiles near the surface of an ice sheet	127
	Temperature distributions far from a divide	131
	Englacial and basal temperatures along a flow line calculated using the Column model	135
	Basal temperatures in Antarctica – comparison of solutions using the Column model and a numerical model	138
	Geomorphic implications	142
	Summary	144
<b>7</b>	<b>The coupling between a glacier and its bed</b>	<b>147</b>
	Sliding	148
	Deformation of subglacial till	168
	Stability of ice streams	190

	Effect of a frozen bed	193
	Summary	194
<b>8</b>	<b>Water flow in and under glaciers: geomorphic implications</b>	<b>197</b>
	The upper part of the englacial hydraulic system	197
	Equipotential surfaces in a glacier	201
	Melt rates in conduits	205
	Water pressures in subglacial conduits on hard beds	208
	Types of subglacial drainage system	215
	Surges	230
	Subglacial drainage paths and the formation of eskers	232
	Tunnel valleys	241
	Water pressure and glacier quarrying	244
	Origin of cirques and overdeepenings	248
	Summary	250
<b>9</b>	<b>Stress and deformation</b>	<b>252</b>
	Stress	252
	Momentum balance	261
	Deformation	262
	Condition that principal axes of stress and strain rate coincide	267
	Summary	269
<b>10</b>	<b>Stress and velocity distribution in an idealized glacier</b>	<b>271</b>
	Solutions for stresses and velocities in plane strain	271
	Comparison with real glaciers	286
	Summary	287
<b>11</b>	<b>Numerical modeling</b>	<b>288</b>
	Goals of modeling	289
	Numerical integration	289
	Finite-difference models	291
	Finite-element models	298
	Initial conditions and forcing	299
	Validation	301

## x Contents

	Intercomparison of models	301
	Sensitivity testing and tuning	302
	Coupling thermal and mechanical models	303
	Examples	304
	Summary	313
<b>12</b>	<b>Applications of stress and deformation principles to classical problems</b>	<b>315</b>
	Collapse of a cylindrical hole	315
	Calculating basal shear stresses using a force balance	326
	Creep of floating ice shelves	333
	Analysis of borehole-deformation data	338
	Summary	348
<b>13</b>	<b>Finite strain and the origin of foliation</b>	<b>349</b>
	The strain ellipse	349
	Simple and pure shear	351
	Parameters describing cumulative deformation	352
	Calculating cumulative strain	353
	Components of foliation	356
	Summary	364
<b>14</b>	<b>Response of glaciers to changes in mass balance</b>	<b>365</b>
	Positive feedback processes	366
	Response of a temperate glacier	367
	Elementary kinematic wave theory	368
	Analysis of the effect of a small change in mass balance using a perturbation approach	371
	Effect of diffusion	375
	The problem at the terminus	376
	Further study of the response time	376
	Numerical modeling of glacier responses	381
	Comparison with observation	383
	Summary	390
	Appendix Problems	391
	References	399
	Index	421