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List of symbols

A	cross-sectional area
A_s, A_z	amplitude of temperature wave at surface and at depth z respectively
C	volumetric heat capacity; cohesion
$C_a(T)$	apparent volumetric heat capacity at temperature T
C_s, C_m, C_o, C_w	volumetric heat capacity, soil, soil minerals, organic material and water respectively
C_v	consolidation coefficient
c	mass heat capacity
c_p	mass heat capacity, air at constant pressure
D_v	diffusion coefficient for water vapour in soil
D_θ	soil moisture diffusivity
E	internal energy
e	saturation vapour pressure over ice
G	free energy (absolute)
Gg	geothermal gradient
ΔG	(relative) free energy
ΔG_l	free energy, liquid phase
ΔG_s	free energy, solid phase
ΔG_i	free energy, ice
ΔG_w	free energy, water
H	component of movement perpendicular to slope
ΔH	change of heat storage
h	vertical depth below water table; height of water column
K	thermal conductivity
K_H	turbulent transfer coefficient
K_v	turbulent transfer coefficient, water vapour
$K\downarrow$	short wave radiation, incoming
$K\uparrow$	short wave radiation, outgoing (reflected)
k	constant; hydraulic conductivity, permeability
k_f	permeability of frozen soil to water substance
L	downslope component of movement
L_f	latent heat of fusion
L_v	latent heat of vaporisation
$L\downarrow$	long wave radiation, incoming
$L\uparrow$	long wave radiation, outgoing
l	length
m_v	coefficient of volume compressibility

P	period of temperature wave; pressure; load (weight) of soil
P_a	gas pressure; air pressure
P_w	water pressure
P_i	ice pressure
Q^*	net radiation (radiative surplus or deficit)
Q_G	ground heat flux
Q_H	sensible heat flux (atmospheric)
Q_{LE}	evaporative–condensative heat flux
q	flow, volume per second; specific humidity; flux of water
q_l	flow, liquid phase
q_f	flux through frozen soil
q_u	flux through unfrozen soil
q_v	mass vapour flow; mass flux per unit area
q_s	specific humidity of surface
q^*	saturation specific humidity
R	thaw-consolidation ratio; gas constant for water vapour
r_a	aerodynamic resistance
r_{aw}	radius of meniscus, air/water
r_{iw}	radius of ice/water interface
S	shear strength; specific surface area
s	entropy
s_i	entropy of ice
s_w	entropy of water
T	temperature
ΔT	depression of freezing point; difference (change) in temperature
T_a	air temperature
T_0	freezing point, normal conditions
T_s	surface temperature
T_z	temperature at depth z
t	time
u	pore water pressure
V	volume; specific volume
V_a	specific volume, air
V_i	specific volume, ice
V_w	specific volume, water
w	soil moisture content (gravimetric)
X_m, X_o, X_w	volume fraction soil minerals, organic material, and water
Z_H	component of depth normal to slope
Z	distance; depth

z_p	depth at which geothermal gradient offsets negative temperature at surface
α	albedo
β	angle of slope
γ	unit weight of soil
γ_w	unit weight of water
ε	emissivity; strain
θ	volumetric moisture content
θ_u	water content of frozen soil (unfrozen water content)
θ_i	volumetric ice content
λ	a period of time
κ	thermal diffusivity
κ_a	apparent thermal diffusivity
ρ	density
ρ_d	dry density of soil
ρ_i	density of ice
ρ_s	bulk density of soil
ρ_w	density of water
σ	normal stress
σ'	effective normal stress
σ_n	neutral stress
σ_1	axial stress
σ_3	confining stress
σ_{aw}	interfacial energy (surface tension) air/water
σ_{iw}	interfacial energy (surface tension) ice/water
τ	shear stress
τ_f	shear stress for failure
ϕ	angle of internal friction
$\chi(\Omega)$	factor relating to stress partition
ψ	moisture potential

Preface

Activities in the cold regions of the earth have expanded greatly in recent decades, largely as a result of interest in natural resources (especially oil, gas and minerals), creating a demand for knowledge of the special natural conditions found there. Over this period there have been improvements in geotechnical engineering and a greater scientific understanding of the effects of freezing and thawing upon earth materials. The benefits of this have also extended to regions which experience significant seasonal freezing and thawing. While there are several texts which describe the terrain features of the cold regions, as well as a large technical literature in the form of research papers and conference proceedings, there appeared to be a need for a textbook which integrated the various approaches inherent in our contemporary understanding of the frozen earth.

Much of our knowledge of geocryology is recent, and has been built upon the extensive work of field scientists, as well as the work of geotechnical engineers. As practical needs have become more pressing, the work of laboratory and theoretical scientists–applying the principles of physical chemistry and thermodynamics–has been of fundamental importance. The challenge of this book was to combine and integrate these, and indeed other perspectives into an effective synthesis, one which could provide students and professionals alike with the basic knowledge appropriate to the study of the unique terrain and geotechnical conditions in cold climates.

We have tried to include sufficient description of the natural terrain in order to understand the significance and effects of the thermal, mechanical and hydrological processes which are characteristic of the cold regions. These processes we have dealt with at several levels: so far as possible basic introductory accounts are given, which outline the physical science involved and which provide a starting point for more detailed accounts given in other chapters. The reader may find some element of repetition, which we hope really represents a progression (not necessarily coincident with the order of the chapters). Many topics, of course, turn out to be related, increasing the need for cross-referencing. Depending on the reader's background, some chapters will inevitably seem more familiar than others. But with the exception of the first chapter, which introduces the range of issues covered, and the last, which summarises current themes in the subject, the order of chapters is not designed with any particular kind of reader in mind. Rather, we hope regardless of the order in which the

chapters are first read, that we have presented a reasonably comprehensive picture of a rapidly developing subject, one which to a high degree builds upon many different branches of intellectual inquiry. While permafrost and related topics are normally the concern of earth scientists, we hope that this book will also be useful to engineers, ecologists, hydrologists and others.

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On a more personal note our thanks are due to Beatrice Williams for advice on thermodynamics and to Pauline Smith for advice on presentation–our families have also contributed by cheerfully accepting our preoccupation with this book.

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