Tropical Glaciers

Georg Kaser and Henry Osmaston
Contents

List of figures and tables  x
Preface  xix
Sub-preface  xx

PROLOGUE: THE STORY OF A GLACIAL LAKE  Georg Kaser  1

I  THE NATURE OF TROPICAL GLACIERS  Georg Kaser  13

1. A brief introduction on the matter  15

2. The delimitation of the tropics  17

3. The distribution of glaciers in the tropics  19

4. Working hypotheses  21
  4.1. A simplified assumption  21
  4.2. How valid is this assumption?  21
  4.3. The variation of the lower snowfall limit  23
  4.4. How tropical are the outer tropics? A second assumption  24
  4.5. Two tropical glacier regimes  25

5. Glaciological key variables: tropics and mid-latitudes in comparison  26
  5.1. The vertical profile of the specific mass balance  26
  5.1.1. The activity index and the vertical mass balance profile of a glacier  26
  5.1.2. The modelling of the vertical mass balance profile  27
  5.1.3. The vertical mass balance profile in the mid-latitudes  28
  5.1.4. The vertical mass balance profile in the tropics  30
  5.1.5. Summary of section 5.1  37
  5.2. The reaction of the equilibrium line altitude to climatic variations  37
  5.3. The reaction of glacier tongues to climatic variations  41
  5.3.1. The length of the tongue in the steady-state case  41
  5.3.2. The reaction of the position of the tongue to climatic changes  45
  5.3.3. Reaction time and response time of glaciers to climatic changes  46
  5.4. The accumulation area ratio of tropical glaciers  48
  5.5. The temperature distribution in the snow cover and its consequences  49
  5.5.1. The temperature distribution in snow and firn under ideal tropical conditions and the expected consequences  49
CONTENTS

5.5.2. Accumulation measurements on tropical glaciers 50
5.5.3. Ice dynamics on tropical glaciers 55
5.6. The influence of the glaciers on the water balance of tropical mountains 57

II MODERN GLACIER FLUCTUATIONS IN TROPICAL HIGH MOUNTAINS  Georg Kaser 61

6. Modern glacier fluctuations on the Rwenzori 63
6.1. The Rwenzori Mountains 63
6.2. The essential features of the climate of the Rwenzori 63
6.3. Glacier research on the Rwenzori 67
6.3.1. Aerial photographs, maps and summarizing publications 68
6.3.2. Modern glacier extents 69
6.4. The 1906 glacier extent 70
6.5. The glacier extent around 1955 76
6.5.1. Mount Stanley 76
6.5.2. Mount Speke 76
6.5.3. Mount Baker 76
6.5.4. The Central Rwenzori Massif 81
6.6. The glacier extent around 1990 84
6.7. The retreat of individual glaciers 84
6.7.1. The Elena Glacier 84
6.7.2. The Speke Glacier 84
6.7.3. The Moore Glacier 99
6.7.4. The Savoia Glacier 100
6.8. Modern glacier fluctuations on the Rwenzori – review 100
6.8.1. Summary 111

7. Modern glacier fluctuations in the Cordillera Blanca 117
7.1. The Cordillera Blanca 117
7.2. Essential features of the climate in the Cordillera Blanca 118
7.3. The glaciology of the Cordillera Blanca 121
7.4. Modern glacier fluctuations 123
7.4.1. A synthesis 126

8. Modern glacier fluctuations in the tropics and their possible causes 130
8.1. Modern glacier fluctuations in the tropics – a synthesis 130
8.2. Possible causes of modern glacier fluctuations in the tropics 135
8.2.1. Basic considerations 135
8.2.2. Possible causes on individual tropical high mountains 137
8.2.3. Summary of section 8.2 146

III FORMER QUATERNARY TROPICAL GLACIERS  Henry Osmaston 147

9. The nature, extents and climates of former Quaternary tropical glaciers, with special reference to the East African mountains 149
9.1. Introduction 149
9.2. The nature of tropical Quaternary glaciers and estimation methods for their ELAs 152
9.2.1. The morphology of the glaciers and their moraines 152
9.2.2. Supraglacial moraine 154
9.2.3. ELA estimation – general principles 155
9.2.4. ELA estimation – methodology 156
9.2.5. Constraints 157
9.2.6. Estimation of ELA changes on tropical mountains 158
9.2.7. Deglacierization dates 160
9.3. Summary of field evidence of former glaciations in the tropics (excluding East Africa) 162
9.3.1. New Guinea (Australasia) 163
9.3.2. Mount Kinabalu (Sabah, East Malaysia) 166
9.3.3. Yu Shan (Taiwan) 166
9.3.4. Mauna Kea (Hawaii) 166
9.3.5. Central America 167
9.3.6. Andes (South America) 167
9.3.7. Ethiopia (Northeast Africa) 168
9.4. The East African mountains 169
9.4.1. Kilimanjaro 171
9.4.2. Mount Kenya 173
9.4.3. Elgon (Uganda and Kenya) 175
9.4.4. Aberdare (= Mt. Nyandarua) (Kenya) 177
9.4.5. Rwenzori (Uganda and Dem. Rep. of Congo) 177
9.5. Tropical climates at the LGM 185
9.5.1. Types of evidence 185
9.5.2. Climates in East Africa 187
9.5.3. Climates elsewhere in the tropics 189
9.5.4. Is there an LGM equatorial glacier type? 189
9.6. Summary 190
9.6.1. The LGM 190
9.6.2. ELA estimation 190
9.6.3. Debris cover 190
9.6.4. Local relief 190
9.6.5. ELA surface gradients and ELA differences 191
9.6.6. Climatic change 191
9.6.7. Atmospheric temperature lapse rates 191
9.6.8. Estimates of temperature change 191
9.6.9. Future studies 191
9.6.10. A new glacier type 192

PROSPECT  Georg Kaser and Henry Osmaston 193

References 195
Index 205