

CAVES

PROCESSES, DEVELOPMENT, AND MANAGEMENT

People have been interested in caves for a very long time. Our distant ancestors used them for shelter, as sources of water, and as places in which to conduct essential rituals. They adorned their walls with quite sophisticated artwork depicting both their existential and spiritual concerns. Caves feature in our mythology, they are used as places of worship in many cultures, and they are used throughout the world as places in which to store prized foodstuffs and wine. For at least two hundred years they have attracted scientists, artists, photographers, and recreational cavers. This book aims examines how caves form, the light they shed on past environments and climates, and the values, both environmental and cultural, that they provide to humanity.

This second edition of **Caves: Processes, Development, and Management** is a welcome revision of the author's earlier treatment released over twenty years ago. It has been updated, significantly expanded, and largely rewritten. The intervening years have seen a dramatic increase in karst and cave research globally, with significant advances in our understanding of fundamental processes, in our ability to extract proxy climatic and environmental data from cave deposits, and in our understanding of the breadth of cave values and as a result the complexity of their management needs. This new edition adopts a broad international perspective in the research examples used and the cited literature, and has actively sought out material from the tropical world and the southern continents, thus avoiding the European and North American bias frequently found in speleological publications.

Caves: Processes, Development, and Management, Second Edition, is organised into four sections. In the first section, contemporary processes of cave formation are examined. The second section of the book deals with past processes and their physical manifestation. In the third section, the use of caves by various organisms from bacteria to humans is explored. The final section of the book reviews our changing approaches to cave management and to catchment management on karst terrains. The book will be of use to anyone who is interested in caves and karst, or who wants to understand about cave formation, development, values and management.

About the Author

David Shaw Gillieson is an Honorary Professorial Fellow at the School of Geography, Earth and Atmospheric Sciences, University of Melbourne, Carlton, Victoria, Australia. He has held academic appointments at the Australian National University, University of New South Wales and James Cook University. Over the last fifty years he has explored and studied caves in Australasia, Europe, North America, Oceania and Southeast Asia. He is currently Treasurer of the Australasian Cave and Karst Management Association, and is a former Chair of the International Geographical Union Commission on Karst. He has been involved in the evaluation and writing of World Heritage nominations, and cave and karst management plans across the globe.

Cover Design: Wiley
Cover Image: © Steven Bourne, used with permission

www.wiley.com

WILEY Blackwell



Also available
as an e-book

ISBN 978-1-119-45557-8



9 781119 455578

Contents

Preface and Acknowledgements *xiii*

1 Introduction 1

1.1 Some Basic Propositions 1

1.2 Now the Details... 3

2 Caves and Karst 6

2.1 What Is a Cave? 6

2.2 What Is Karst? 7

2.3 Caves as Systems 9

2.3.1 Caves as Geomorphic Systems 10

2.3.2 Caves as Biological Systems 13

2.4 Where Are the Deepest and Longest Caves? 14

References 16

3 Cave Hydrology 18

3.1 Basic Concepts in Karst Drainage Systems 18

3.2 Porosity and Permeability 20

3.2.1 Diffuse Flow 20

3.2.2 Fissure Flow 22

3.2.3 Conduit Flow 22

3.2.4 Understanding the Karst Drainage System 25

3.3 Zonation of the Karst Drainage System 27

3.4 Defining the Catchment of a Cave 30

3.5 Analysis of Karst Drainage Systems 32

3.5.1 Water-Tracing Techniques 32

3.5.2 Spring Hydrograph Analysis 35

3.5.3 Spring Chemograph Analysis 40

3.6 Structure and Function of Karst Drainage Systems 41

3.6.1 Storage and Transfers in the Karst System 41

3.6.2 The Role of Extreme Events 43

3.7 Karst Hydrology of the Mammoth Cave Plateau, Kentucky 47

References 51

4	Processes of Rock Dissolution	55
4.1	Introduction	55
4.2	Karst Rocks	55
4.2.1	Limestone	55
4.2.2	Dolomite	62
4.2.3	Evaporite Rocks—Gypsum and Halite	63
4.2.4	Sandstone	64
4.2.5	Granite	65
4.3	Processes of Dissolution of Karst Rocks	66
4.3.1	The Solution of Limestone in Meteoric Waters	66
4.3.2	Soil and Vegetation in the Limestone Solution Process	68
4.3.3	The Zoning of Solution in the Unsaturated Zone	70
4.3.4	Limestone Solution in Seawater	71
4.4	Hydrothermal Solution of Limestone	73
4.5	Solution of Evaporites	74
4.6	Solution of Silicates in Meteoric Waters	75
4.7	Caves in Quaternary Limestone in Southern Australia	77
	References	83
5	Speleogenesis	86
5.1	Classifying Cave Systems	86
5.2	Controls of Rock Structure on Cave Development	89
5.2.1	Role of Lithology	89
5.2.2	Role of Joints, Fractures, and Faults	90
5.2.3	Cave Breakdown and Evaporite Weathering	94
5.3	Meteoric Speleogenesis, Unconfined and Confined	96
5.3.1	Formation of Caves in Plan	96
5.3.2	Formation of Caves in Length and Depth	97
5.3.3	The Formation of Maze Caves	103
5.3.4	Tectonic and Eustatic Controls on Cave Development	105
5.3.5	Deep Shafts of the World	114
5.4	Hypogene Speleogenesis	115
5.4.1	Solutional Mesoforms as Indicators of Hypogene Origin	117
5.4.2	Condensation and Corrosion in Passage Enlargement	117
5.5	Flank Margin Speleogenesis	120
5.6	Caves Formed in Gypsum	122
5.7	Lava Tubes, Weathering Caves, and Pseudokarst	123
5.7.1	The Formation of Lava Tubes	123
5.7.2	Weathering Caves and Pseudokarst	126
5.8	Life History and Antiquity of Caves	126
5.9	Geological Control and the World's Longest Cave	127
	References	133
6	Cave Interior Deposits	138
6.1	Introduction	138

6.2	Carbonates	144
6.3	Controls over Carbonate Mineralogy	148
6.4	Other Cave Deposits Formed by Carbonate Minerals	149
6.5	Growth Rates of Speleothems	151
6.6	Important Non-carbonate Minerals	153
6.6.1	Evaporites (Sulphates and Halides)	153
6.6.2	Phosphates and Nitrates	155
6.6.3	Oxides, Silicates, and Hydroxides	156
6.7	Ice in Caves	157
6.8	Other Minerals	158
6.9	Cave Deposits of the Nullarbor Plain, Australia	158
	References	166

7 Cave Sediments 171

7.1	Introduction	171
7.2	Clastic Sediment Types	171
7.3	Processes of Sedimentation	172
7.3.1	Gravity-Fall Processes	172
7.3.2	Waterlain Clastic Sediments	175
7.3.3	Cave and Rockshelter Entrance Deposits	184
7.4	Sediment Transport and Particle Size	185
7.5	Diagenesis of Cave Sediments	188
7.6	Stratigraphy and its Interpretation	189
7.7	Provenance Studies	190
7.8	Cave Sediments and Environmental History at Zhoukoudian, China	191
	References	195

8 Dating Cave Deposits 198

8.1	The Importance of Dating Cave Deposits	198
8.2	Dating Techniques and the Quaternary Timescale	199
8.3	Palaeomagnetism	200
8.4	Uranium Series; Uranium-Thorium, Uranium-Lead	203
8.5	Radiocarbon	211
8.6	Other Dating Methods: Cosmogenic Radionuclides, and Tephrochronology	213
8.7	Timing Glacial and Interglacial Events in New Zealand	215
	References	221

9 Cave Deposits and Past Climates 225

9.1	Introduction	225
9.2	Oxygen Isotope Analysis	226
9.3	The Last Glacial-Interglacial Temperature Record	228
9.4	Carbon Isotopes and Environmental Changes	234
9.5	Cyclone History in the Indo-Pacific Region	235

- 9.6 Other Proxy Records (Trace Elements, Annual Laminae, Pollen, Lipid Biomarkers) 239
- 9.7 The Long Environmental History of the Nullarbor Plain, Australia 240
- 9.8 Some Speculations on the Future 245
- References 245

10 Cave Ecology 248

- 10.1 Introduction 248
- 10.2 Classification of Cave Life and its Function 248
- 10.3 Adaptations and Modifications to Life in Darkness 249
- 10.4 Life Zones within Caves 252
- 10.5 The Cave as a Habitat 255
- 10.6 Energy Flows in Cave Ecosystems 261
- 10.7 Cave Microbiology 264
- 10.8 Origin and Dispersal of Cave-Dwelling Animals 267
- 10.9 Threats to Cave Fauna 270
- 10.10 Conservation of Biological Diversity in Caves 275
- 10.11 Caves and Ecosystem Services 277
- 10.12 White Nose Syndrome 280
- 10.13 Unravelling the Secrets of the Carrai Bat Cave 283
- References 286

11 Cave Archaeology 292

- 11.1 Introduction 292
- 11.2 Prehistoric Uses of Caves 293
- 11.3 Cave Faunas and Hominids 294
- 11.4 Cave Art in Context 300
- 11.5 Depositional Environments in Caves 304
- 11.6 Cave Deposits and Biological Conservation 305
- 11.7 Taphonomy of Cave Deposits 306
- 11.8 Archaeology of Liang Bua Cave, Flores (the Hobbit Cave) 309
- References 315

12 Historic Uses of Caves 318

- 12.1 Introduction 318
- 12.2 Caves as Shelter 318
- 12.3 Caves as Sacred Spaces 321
- 12.4 Caves as Sources of Raw Materials 324
- 12.5 Cave Tourism 333
- 12.6 Cave Dwellings in Turkey 335
- References 340

13 Cave Management 342

- 13.1 Introduction – Caves as Contested Spaces 344
- 13.2 Interpretation and Guide Training 345

13.3	Cave Lighting	348
13.4	Some Engineering Issues in Caves	349
13.5	Impacts of Visitors and Infrastructure on Show Caves	352
13.6	Radon Risk in Caves	358
13.7	Cave Cleaning and its Impacts	362
13.8	Impacts of Recreational Caving on Caves	362
13.9	Cave Rescue	367
13.10	Cave Inventories and Alternative Management Concepts	371
13.11	Rehabilitation and Restoration of Caves	374
13.12	Cave Classification and Management	376
13.13	Policy Approaches to Cave and Karst Protection	378
13.14	Management of the Gunung Mulu World Heritage Area, Sarawak, Malaysia	379
	References	388

14 Catchment Management in Karst 393

14.1	Introduction	393
14.2	Basic Concepts in Karst Management	393
14.3	Defining Karst Catchments	395
14.4	Vegetation and Caves	398
14.5	Accelerated Soil Loss in Karst	400
14.6	Agricultural Impacts	402
14.6.1	Rocky Desertification	402
14.6.2	Infilling of Dolines	403
14.6.3	Altered Drainage	404
14.6.4	Groundwater Lowering	405
14.6.5	Fertiliser and Herbicides	407
14.6.6	Pesticides	408
14.6.7	Microbial Contamination of Groundwater	409
14.6.8	Golf Courses on Karst	411
14.7	Fire Management in Karst	412
14.8	Conservation Issues in Karst	414
14.9	Assessing Vulnerability in Karst Management	415
14.9.1	Karst Disturbance Index	415
14.9.2	Karst Groundwater Vulnerability	417
14.9.3	Data Availability	418
14.10	Understanding Disputes Over Cave and Karst Resources	421
14.11	The IUCN Guidelines for Cave and Karst Protection	423
	References	426

15 Documentation of Caves 432

15.1	Geoheritage Assessment	432
15.2	Cave Mapping	436
15.3	Cave Photography	442
15.4	3D Scanning of Caves	449

15.5	Drones	453
15.6	Mapping World Heritage Caves in Gunung Mulu National Park, Malaysia	454
	References	457
	Glossary of Cave and Karst Terminology	461
	Further Reading	474
	Index	475