The SAGE Handbook of Geomorphology

Edited by

Kenneth J. Gregory and Andrew S. Goudie

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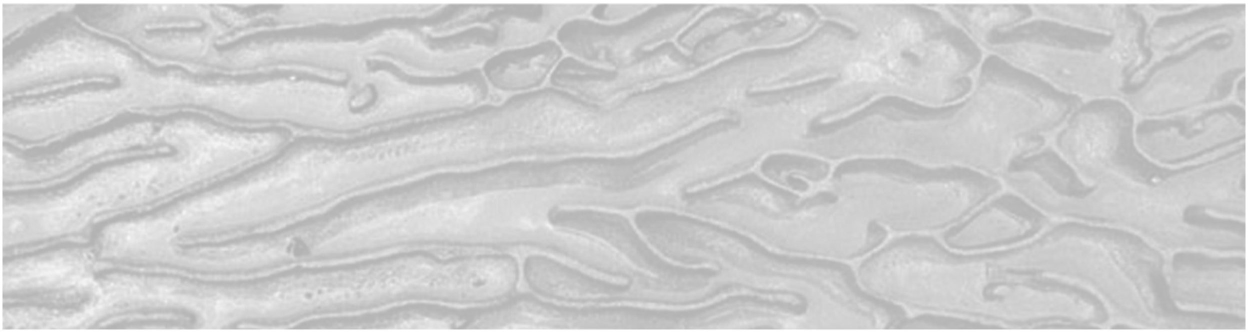

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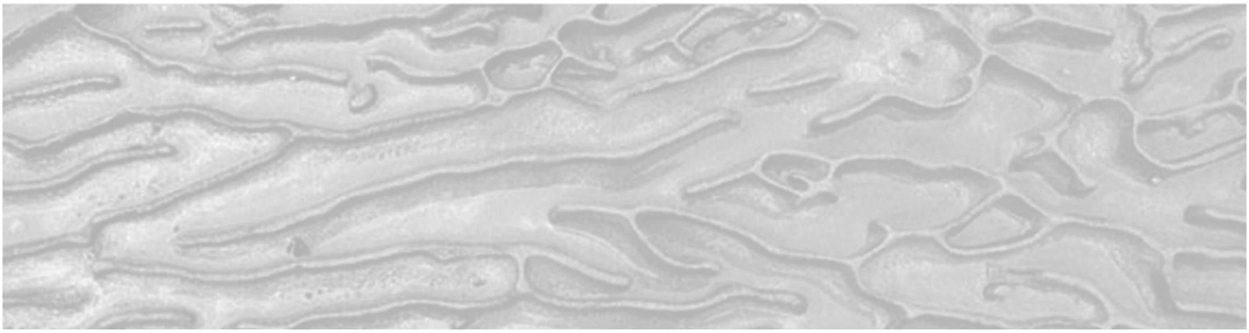

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SAGE

Los Angeles | London | New Delhi
Singapore | Washington DC

First published 2011

SAGE Publications Ltd
1 Oliver's Yard
55 City Road
London EC1Y 1SP

SAGE Publications Inc.
2455 Teller Road
Thousand Oaks, California 91320

SAGE Publications India Pvt Ltd
B 1/I 1 Mohan Cooperative Industrial Area
Mathura Road, Post Bag 7
New Delhi 110 044

SAGE Publications Asia-Pacific Pte Ltd
33 Pekin Street #02-01 Far East Square
Singapore 048763

Library of Congress Control Number 2010939890

British Library Cataloguing in Publication data
A catalogue record for this book is available from the British Library

ISBN 978-1-4129-2905-9

Typeset by Glyph International, Bangalore, India
Printed in Great Britain by MPG Books Group, Bodmin, Cornwall
Printed on paper from sustainable resources

Contents

Acknowledgements

This Handbook, initiated by members of the International Association of Geomorphologists (IAG), has evolved considerably in content during the preparation of the chapters. Basil Gomez assisted by André Roy and Vic Baker contributed to the establishment of the basis for the volume during the early stages. I was brought in at a later stage and have been most grateful to Andrew Goudie for the many excellent ways in which he has provided help and support to get the Handbook to its final conclusion. Thanks are also expressed to the publishers especially Robert Rojek for the initial discussions and to Sarah-Jayne Boyd who has fended my many queries.

We are extremely grateful to all the contributors not only for preparing their chapters, but for contributing royalties to the IAG, and for their patience in awaiting the culmination of such an extensive project.

Kenneth J. Gregory

List of Contributors

Victor R. Baker is Regents' Professor of Hydrology and Water Resources, Geosciences and Planetary Sciences, University of Arizona. His 350 research papers and chapters concern palaeohydrology, planetary geomorphology and history/philosophy. His 16 books include *Catastrophic Flooding* (1981), *The Channels of Mars* (1982), *Flood Geomorphology* (1988, co-edited), *Ancient Floods, Modern Hazards* (2002, co-edited) and *Megaflooding on Earth and Mars* (2009, co-edited). He was the 1998 President of the Geological Society of America (GSA) and his honours include GSA Distinguished Scientist and Distinguished Career Awards, Foreign Membership in the Polish Academy of Sciences, Honorary Fellowship in the European Union of Geosciences and the David Linton Award of the BSG.

Paul Bierman is a geomorphologist with wide-ranging interests including environmental geology, hydrology, isotope geochemistry, glacial geology, surface process and rates of weathering and denudation. He works at the interface between active research, education and science literacy at all levels. He received his degrees from Williams College and the University of Washington. He directs UVM's Cosmogenic Nuclide Extraction Lab - one of only a handful of laboratories in the country dedicated to the preparation of samples for analysis of 10-Be and 26-Al from pure quartz (uvm.edu/cosmolab). He is the recipient (1996) of the Donath Medal as the most promising young geologist in the country. He was also the recipient of NSF's highest award, the Director's Award for Distinguished Teaching Scholars, in 2005.

Paul Bishop has been Professor of Physical Geography in the University of Glasgow since 1998. His undergraduate degree is from the School of Earth Sciences at Macquarie University in Sydney, as are his PhD and recently awarded DSc. His research focuses principally on long-term landscape evolution, with a key interest being the ways in which tectonics and surface processes interact, as mediated by bedrock rivers. Low-temperature thermochronology and cosmogenic nuclide analysis are key techniques for that research, which has always been undertaken with teams of post-doctoral researchers and PhD students.

Derek Booth is Affiliate Professor in the departments of Earth and Space Sciences and Civil and Environmental Engineering at the University of Washington, where he was previously a research professor until 2006. He has studied geomorphology, hydrology and watershed management for the past 30 years with the US Geological Survey, with the Basin Planning Program for King County (Washington), in academia and now in private practice. He is presently the president and senior geologist at Stillwater Sciences, an environmental consulting firm active in stream and watershed analysis in California, Oregon and Washington; and the senior editor of *Quaternary Research*. His interests are river dynamics and deposits, urban watershed management and stormwater, landscape processes and geologic hazards. His work emphasizes field-based collection and analysis of basic physical data crucial to understanding landscape conditions and watershed processes and their likely responses to human disturbance.

Tony G. Brown was originally appointed as a lecturer in Soils at the University of Leicester having completed a PhD on Holocene fluvial geomorphology and palaeoecology at the University of Southampton. Since the 1980s his research has focussed on Quaternary and particularly Holocene fluvial geomorphology floodplain environments with a particular interest in geochronology and human environmental impact. In 1991, and after moving to the University of Exeter in 1993, he directed the Quaternary Palaeoenvironments Research Group. In 2009, he took up his present post as Director of the Palaeoenvironment Laboratory at the University of Southampton (PLUS). He has published over 150 refereed research articles, edited five books and is author of the standard research monograph *Alluvial Geoarchaeology* CUP (1997) and a recent review of floodplain geoarchaeology (*Aggregate-related Archaeology: Past, Present and Future*. Oxbow) commissioned by English Heritage. Over the last 20 years he has received research project funding from NERC, English Heritage, AHRC, Leverhulme, HLF and industry.

Joanna Bullard is a Reader in Aeolian Geomorphology at Loughborough University. She completed her undergraduate degree at the University of Edinburgh and her PhD at the Sheffield Centre for International Drylands Research, Sheffield University, investigating the geomorphological variability of linear sand dunes in the southwest Kalahari, southern Africa. Her current research focuses on aeolian processes and landforms and includes determining geomorphological controls on dust emissions from the Simpson-Strzelecki Desert, Australia and the development of dunefields in the Atacama Desert, South America. Her research has taken her to environments ranging from the forests of Central America to the proglacial sandur plains of Iceland and Greenland. A particular interest is in the interaction between different geomorphological process systems and she is currently exploring the interaction between glacifluvial and aeolian processes in West Greenland. She is the physical geography editor of the RGS-IBG Book Series and an associate editor for the journal *Earth Surface Processes and Landforms*.

Michael Church is Emeritus Professor at the University of British Columbia, where he taught courses in environment and resources, hydrology, geomorphology, field studies and research methods for 38 years. His research interests focus on fluvial sediment transport and the interpretation of river channel changes. He has, throughout his career, also participated in practical work on water management in forestry, mining and fisheries, and has worked extensively on management issues on large rivers. He is a registered Professional Geoscientist in British Columbia.

Nicholas J. Clifford is Professor of Physical Geography at King's College London and completed his undergraduate and postgraduate degrees at the University of Cambridge. He is a fluvial geomorphologist, with interests in numerical simulation of flows and habitats in rivers; in river restoration and management; and in the broader field of environmental time series analysis. He has held appointments at University College London and the University of Nottingham, and has published widely in the fields of geomorphology, physical geography and geographical philosophy and methods. He is co-editor of Sage's *Key Concepts* and *Key Methods in Geography*, and is Managing Editor of the journal *Progress in Physical Geography*.

Peter Cowell is head of school in the School of Geosciences at the University of Sydney and Director of the University of Sydney Institute of Marine Science. His has undertaken more than 25 years research on coastal and continental-shelf sediment deposits. This work has included how these deposits were formed under the influence of long-term changes in sea level and other environmental factors. The results of these studies have been used to develop computer models that simulate the formation of known deposits over past centuries and millennia, and these models have been adapted to forecast future coastal impacts of climate change over coming decades and centuries based on geological calibration. The work has been widely published internationally, and has involved collaboration with leading coastal scientists in Australia, New Zealand, The Netherlands, the UK, Italy, the USA and Brazil, where the models have been trialed under a wide range of environmental conditions.

Michael Crozier is Professor Emeritus at Victoria University of Wellington holding a personal Chair in Geomorphology from 1998. He is President of the International Association of Geomorphologists, past president of the New Zealand Geographical Society and former member of the New Zealand Conservation Authority. Academic awards include a Fulbright Scholarship to USA, Leverhulme fellowship to

University of Bristol and a Distinguished Visiting Professorship at the University of Durham. He has held academic positions at the Universities of Otago, Alberta, Trent and Vienna. His research focus includes landslides, natural hazards, and human impact on natural systems.

Mark Dickson is a coastal geomorphologist at the University of Auckland. He obtained a BSc from Massey University and a PhD from the University of Wollongong. He worked as a postdoctoral researcher at the University of Bristol and a FRST postdoctoral research fellow at the National Institute of Water and Atmospheric Research (NZ). His research is focused on eroding cliffed coastlines, employing both field methods and numerical modelling.

Peter Downs was until recently a consulting fluvial geomorphologist with Stillwater Sciences in Berkeley, California before joining the University of Plymouth as a Senior Lecturer in Physical Geography. He was previously a Lecturer in Geography at the University of Nottingham after obtaining his BSc and PhD degrees at the universities of Leicester and Southampton respectively. His research interests include catchment- and reach-scale sediment budgets, the dynamics and sensitivity of river channels, applications of geomorphology to river basin management, and river restoration planning, design and evaluation. The research has occurred in widely varying fluvial environments in the UK, California, Mississippi and New Zealand, and has frequently been interdisciplinary, linking riverine dynamics to aquatic habitat provision, biological response, flood control, and river instability management. He has published widely including the co-authored text *River Channel Management: Towards sustainable catchment hydrosystems* (2004). He was awarded Chartered Geographer status in 2005, and currently sits on the editorial board of the Institution of Civil Engineers' *Water Management* journal.

Tom Farr received BS and MS degrees from Caltech, and a PhD from the University of Washington, all in Geology. After a short time as an engineering geologist, he joined the Radar Sciences Group at the Jet Propulsion Laboratory, where he has been since 1975. At JPL, he helped develop the first geologic applications of imaging radar using aircraft, satellites and the Space Shuttle. He has also been a science investigator on European and Japanese satellite programs and has assisted in the interpretation of radar images from Venus and from Saturn's moon Titan. His scientific research includes the use of remote sensing and digital topographic data for study of landscapes on Earth and other planets, including how they are formed and modified by climate and tectonic or volcanic activity.

Derek Ford grew up in the limestone city of Bath, England, and began caving and climbing in the nearby Mendip Hills at age 12. He graduated BA Hons, DPhil in geography at Oxford University, taught in geography and geology at McMaster University, Ontario, Canada, and is now Emeritus Professor. His area of research interest has been karst, including hydrogeology, cave genesis, landforms, palaeokarst, clastic and precipitate deposits, dating and palaeoenvironmental studies of speleothems. He has undertaken field research or directed graduate research in Canada, USA, Caribbean and Latin America, and collaborative research throughout Europe and in China; 50 MSc and PhD students supervised to completion, 20 post-doctoral fellows and foreign visiting scientists; over 200 refereed journal papers or chapters, 12 books written or edited, many consulting reports (particularly for Parks Canada), one coffee table book, producer of one movie for the National Film Board of Canada. President, Canadian Association of Geographers International Spelelogical Union. Honours include FRS Canada, medals, career awards and honorary fellowships from 14 nations.

Hugh French obtained his PhD degree from the University of Southampton, UK, in 1967. He taught at the University of Ottawa, Canada, in the departments of geography, geology and earth sciences and was dean of the Faculty of Science, president of the International Permafrost Association and founder and editor-in-chief of the international journal *Permafrost and Periglacial Processes*. He received the Roger Brown Award of the Canadian Geotechnical Society for 'outstanding contributions to permafrost science and engineering' in 1989 and the Canadian Association of Geographers Award 'for scholarly distinction in geography' in 1995. He is now Emeritus Professor, University of Ottawa. His undergraduate text, *The Periglacial Environment, Third Edition*, 2007, was first published in 1976 and subsequently revised in 1996; it has been the international standard for more than 30 years. He has conducted field research in most parts of northern Canada, the Canadian High Arctic islands, central and northern Alaska, Svalbard, northern Siberia, the Qinghai-Xizang (Tibet) Plateau, and Antarctica, and Pleistocene periglacial investigations in southern England, central Poland and the New Jersey Pine Barrens, eastern USA.

Andrew Goudie was at the School of Geography, Oxford University, became fellow of Hertford College, and was appointed Professor of Geography and head of department. In October 2003, he became Master of St Cross College, Oxford. He has been an honorary secretary and vice Pesident of the Royal Geographical Society, executive secretary and chairman of the British Geomorphological Research Group, a member of the Council of the Institute of British Geographers, and president of the Geographical Association, and president of the International Association of Geomorphologists. In 1991, he was awarded the Founders' Medal of the Royal Geographical Society and the Mungo Park Medal by the Royal Scottish Geographical Society; in 2002 a medal from the Royal Academy of Belgium and a DSc by Oxford University. In 2007, he received the Geological Society of America's Farouk El-Baz Award for Desert Research. His research interests include the geomorphology of deserts, climatic change, environmental archaeology and the impact of humans on the environment. He has worked extensively in South Africa, Botswana, Swaziland and Namibia and in Oman, Jordan, Bahrain and the United Arab Emirates. He is the author or co-author of the following books *Geomorphological Techniques* (1981, 1990), *Chemical Sediments and Geomorphology* (1983), *The Geomorphology of England and Wales* (1990), *Salt Weathering Hazards* (1997), *Aeolian Environments, Sediments and Landforms* (1999), *Great Warm Deserts of the World* (2002), *Encyclopedia of Geomorphology* (2004), *Desert Dust in the Global System* (2006), *The History of the Study of Landforms* (volume 4) (2008), *Geomorphological Hazards and Disaster Prevention* (2010) and *Landscapes and Geomorphology* (2010).

Kenneth J. Gregory was Warden of Goldsmiths College University of London and is now Emeritus Professor of the University of London and Visiting Professor of the University of Southampton. He obtained his BSc, PhD and DSc from the University of London. He was made CBE in 2007 for services to geography and higher education, is a fellow of University College London, a former secretary and chairman of the British Geomorphological Research Group, and currently president of the British Society for Geomorphology. His research interests are in river channel change and management, palaeohydrology and the development of physical geography. Recent publications include *The Changing Nature of Physical Geography* (2000), *River Channel Management* (with Peter Downs, 2004), and *The Earths Land Surface* (2010). He edited *Palaeohydrology: Understanding Global Change* with Gerardo Benito (2003), *Physical Geography* (2005) and was lead editor for *Environmental Sciences: A Companion* (2008). He has three Honorary degrees, awards received include the Founder's Medal of the Royal Geographical Society (1993), the Linton award of the BGRG (1999) and the Geographical medal of the Royal Scottish Geographical Society (2000).

Richard Huggett is a Reader in physical geography in the University of Manchester. He obtained his BSc and PhD from University of London. His recent publications include *Topography and the Environment* (with Joanne E. Cheesman, 2002), *Fundamentals of Biogeography* (2nd edn, 2004), *Physical Geography: A Human Perspective* (with Sarah Lindley, Helen Gavin, and Kate Richardson, 2004), *The Natural History of the Earth: Debating Long-term Change in the Geosphere and Biosphere* (2006), *Physical Geography: The Key Concepts* (2010), and *Fundamentals of Geomorphology* (3rd edn, 2011).

Vishwas Kale is a Professor in the department of geography, University of Pune, India. He obtained his MS in geography from the University of Pune and his PhD in archaeology at the Deccan College, Pune. His research interests include fluvial and flood geomorphology, palaeohydrology, Quaternary geomorphology and landscape evolution. He has published over 20 research papers in these topics. With Hervé Piégay, he peer-reviewed international journals and jointly authored a textbook on *Introduction to Geomorphology*. He is on the editorial board of the journal *Geomorphology*.

G. Mathias (Matt) Kondolf is a fluvial geomorphologist and Professor of Environmental Planning at the University of California, Berkeley. He holds a PhD in geography and environmental engineering from the Johns Hopkins University, a MS in earth sciences from the University of California Santa Cruz and an AB in geology *cum laude* from Princeton University. He teaches courses in hydrology, river restoration, and environmental science. He conducts research on aspects of environmental river management, including sediment management in regulated rivers, geomorphic and ecological processes in river restoration, and resolving conflicts among restoration goals, and he frequently advises government and international agencies in the United States and abroad on these topics. With Hervé Piégay, he is co-editor of *Tools in Fluvial Geomorphology* (2003).

Hélène Lamarre is a research assistant at the Canadian Research Chair in Fluvial Dynamics, University of Montreal. She obtained her PhD degree from the University of Montréal in 2006, her thesis investigating sediment transport, sedimentary structures and bed stability in step-pool channels. She contributed to the development of a new approach to track individual particles in order to quantify bed load transport in gravel-bed rivers. The method is based on the insertion of passive integrated transponders in clasts of different sizes and shapes. This cost-effective approach is now used by many geomorphologists in Québec and Europe to link sediment transport to channel hydraulics and morphology. Her current research interests focus on the interaction between flow velocity, bed stability and bed load transport in gravel-bed rivers with a wide range of slope and channel morphology. Her research has been in the south of Québec and in the French Alps, and recent work has been published in *Geomorphology*, *Earth Surface Processes and Landforms* and *Journal of Sedimentary Research*. Since 2002, she lectures to bachelor students on hydrologic processes that operate at or near Earth's surface.

Stuart Lane is Professor of Physical Geography and Director of the Institute of Hazard, Risk and Resilience in Durham University. His research is concerned with the mathematical modelling and analysis of geomorphological and hydrological processes, including river flows, sediment and solute transport, river morphology, river habitat and flood risk. His work is unusual in that it has focused upon innovative collaborations across disciplines and he has worked with engineers, earth scientists, mathematicians, biologists and social scientists, amongst others. He has published over 170 papers, edited three research monographs and is currently Managing Editor of the journal *Earth Surface Processes and Landforms*. He has been awarded two best paper prizes, the Jan de Ploey award from the International Association of Geomorphologists, a Philip Leverhulme Prize for Earth and Environmental Science and an award from the Association of Rivers Trusts for contributions to science.

Andreas Lang has been Chair of Physical Geography at the University of Liverpool since 2003 and Head of the Department of Geography since 2007. He obtained his PhD at the University of Heidelberg, Germany in 1995. Before taking on his current position he was employed as postdoctoral researcher at the Max-Planck Institute for Nuclear Physics in Heidelberg (1995–98) and at the University of Bonn (1998–2001), and as Senior Lecturer at the University Leuven (Belgium, 2001–03). Currently he is the Chairman of the British Society for Geomorphology. His research interests are focused on longer-term landscape evolution – especially the changing sediment fluxes in river systems in response to climate change and human impact. He is also involved with developing and applying geochronological techniques and has been influential in introducing dosimetric dating in geomorphological research.

Dénes Lóczy was research fellow at the Geographical Research Institute of the Hungarian Academy of Sciences for 18 years until 1997, when he moved to the University of Pécs where he is Director of the Institute of Environmental Sciences. He studied Geography and English at Eötvös Loránd University, Budapest, and habilitated at the University of Pécs. He published a handbook *Land Evaluation* (2002) and a two-volume university text-book *Geomorphology* (2005, 2008), both in Hungarian, co-edited collections of papers for Hungarian publishers, Gebrüder Borntraeger and Springer Verlag and wrote 120 academic papers, partly in Hungarian, partly in English. In 1992 he was Alexander von Humboldt scholarship holder in Darmstadt, Germany. Between 2001 and 2005 he was Secretary of the International Association of Geomorphologists. He is a member of the Editorial Boards of *Zeitschrift für Geomorphologie* (Stuttgart) and *Studia Geomorphologica Carpatho-Balkanica* (Kraków).

Anne Mather is Reader in Earth Sciences in the School of Geography, Earth and Environmental Sciences at the University of Plymouth. She completed her undergraduate degree at the University of Hull and her PhD at the University of Liverpool. Her current research focuses on long-term environmental change in tectonically active, dryland areas, involving the direct and indirect responses of alluvial and fluvial systems to regional tectonics and embracing landform and environmental landscape reconstruction on 10^3 to 10^6 year time scales and catchment/basin spatial scales. Her main geographical areas of research include Spain, Turkey, Morocco and Chile.

John Menzies is currently Professor of Earth Sciences and Geography at Brock University. He received his BSc (Hons) degree in geography from the University of Aberdeen and his PhD from the University of Edinburgh. His research interests are in the mechanics of drumlin formation, in subglacial environments, in the rheology of subglacial sediments and in glacial micromorphology in Quaternary sediments and pre-Quaternary sedimentary rocks. He is the editor/author of *Modern Glacial Environments*, *Past Glacial Environments* and the revised student edition of *Modern and Past Glacial Environments*. He is on the editorial board of *Sedimentary Geology*.

Cherith Moses is a senior lecturer in physical geography at the University of Sussex. She graduated with a BSc in geography and a PhD in geomorphology from Queen's University Belfast during which time she was also a research fellow at the Australian National University. Her research focuses on field and laboratory monitoring and measuring of rock weathering and surface change to further understanding of environmental and climatic impacts on landform development. She has a particular interest in limestone landscapes, interactions of weathering processes and weathering with erosion, and applies rock weathering research to the study of building stone decay and the development of rock coasts. She has conducted field research in Australia, Asia, Europe and North Africa.

Nicholas A. Odoni is a researcher at the Institute of Hazard, Risk and Resilience in Durham University. His research is concerned with the development of innovative landscape models in both geomorphology and hydrology. He is also interested in more general problems in geomorphological modelling, in particular the application of experiment design and metamodelling techniques to clarify model emergent behaviour and uncertainty. His PhD research at the University of Southampton was concerned with models of long-term catchment evolution, and addressed the problem of exploring model equifinality in an exemplar landscape evolution model. His more recent work in Durham has been concerned with interactive modelling of diffuse interventions in river catchments to reduce flood risk.

Takashi Oguchi is Vice-Director and Professor at the Centre for Spatial Information Science, The University of Tokyo, Japan. He received his PhD in Geography from The University of Tokyo, and broadened his experience at the University of Arizona, Colorado State University, and the Centre for Ecology and Hydrology (UK). He has participated in research projects on fluvial/hillslope geomorphology, geomorphometry, geoarchaeology, water quality and spatial databases. He has been one of the three editors-in-chief of *Geomorphology* (Elsevier) since 2003, and on the editorial board of *Catena* (Elsevier), *Geographical Research* (Blackwell), *Geography Compass* (Blackwell) and *Open Geology Journal* (Bentham Science).

Hervé Piégay is Research Director at the National Centre of Scientific Research, working at École Normale Supérieure of Lyon where he is a co-director of a research unit of 200 persons. He received his PhD at the University Paris IV – Sorbonne focusing on interactions between riparian vegetation and channel geomorphology. He has led research on the contemporary history of rivers and their catchments, underlining human controls on environmental changes, wood in rivers, floodplain and former channel sedimentation, geomorphology and society, with specific research on human perceptions of river environments. He is involved in integrated sciences and interacts with practitioners providing knowledge for river management, planning and restoration and methodological frameworks and tools using GIS and remote sensing. He is mainly involved in the Rhône basin but also on the Rhine, in Indonesia (Progo), Vietnam (Mekong), USA (Sacramento), and Italy (Magra). He has edited books including *Tools in Fluvial Geomorphology* (with M.G. Kondolf, 2003) and *Gravel-bed Rivers 6*: *From Process Understanding to*

River Restoration (with H. Habersack and M. Rinaldi, 2007). He is associate editor of *Geodinamica Acta* (Lavoisier) and is on the editorial board of *Geomorphology* (Elsevier).

Colin Pain recently retired from Geoscience Australia where he led the team that developed a system of regolith mapping used widely in Australia. He received BA and MA degrees in Geography at the University of Auckland and a PhD in Geomorphology at the Australian National University. He has worked on landforms and landscape evolution in Papua New Guinea, the Philippines and Arizona. His research interests include the relationships between regolith and landforms and the application of digital elevation models and satellite imagery to landform mapping and research. He is on the editorial board of the *Journal of Maps*. He is currently based in Dubai where he is team leader of the Soil Survey of the Northern Emirates, and holds an honorary position in the MED-Soil Research Group at the University of Sevilla.

David Petley is the Wilson Professor of Hazard and Risk at Durham University. His research focuses upon landslide and rockfall mechanics, using a combination of state-of-the-art field monitoring techniques and bespoke laboratory testing. He is the director of the International Landslide Centre at Durham, with research interests in the UK, Europe, South and East Asia, and Australasia, and vice president of the Natural Hazards Division of the European Geosciences Union. He has written over 80 academic papers, and is co-author with Keith Smith of the leading textbook on natural hazards, *Environmental Hazards – Assessing Risk and Reducing Disaster*.

Jonathan Phillips is Professor of Earth Surface Systems in the department of geography, University of Kentucky, and Chief Scientist for Copperhead Road Geosciences, LLC. His research interests are in fluvial and soil geomorphology, biogeomorphology and nonlinear dynamics of earth surface systems. After receiving a BA from Virginia Tech and an MA from East Carolina, he earned his PhD in Geography at Rutgers. He has held previous academic appointments at Arizona State, East Carolina and Texas A&M Universities. He has published extensively in the earth and environmental sciences.

Jim Pizzuto is a fluvial geomorphologist in the department of geological sciences, University of Delaware who has published papers in the last 25 years on a variety of topics, including river bank erosion, the evolution of sediment pulses, floodplain evolution, the influence of land use and climate change on rivers, dam removal, and the transport and storage of sediment and contaminants in fluvial systems.

Bruce L. Rhoads is Professor and head of the Department of Geography at the University of Illinois. His research programme consists of three distinct, but interrelated areas of interest: integrated watershed science in human-dominated environments, including stream channelization and naturalization; basic research on the dynamics of meandering rivers and river confluences; and the philosophical and methodological underpinnings of geomorphology and the relation of these to those of geography, geology and other sciences.

Keith Richards is Professor of Geography at the University of Cambridge, and a fellow of Emmanuel College. He is a fluvial geomorphologist whose research interests focus on river channel forms and processes in a wide range of environments; hydrological processes and sediment production and transfer processes in river basins; and the modelling of fluvial and hydrological systems. He has had interests in river and floodplain restoration, inter-relationships between hydrological and ecological processes in floodplain environments, and glacial hydrology. He is a former secretary and chairman of the British Geomorphological Research Group, and a former vice president (research) of the Royal Geographical Society/Institute of British Geographers. He has published some 200 papers, is the author or co-author of *Rivers: Form and Process in Alluvial Channels* (1982; 2004 facsimile) and *Arsenic Pollution: A Global Synthesis* (2009); and editor or co-editor of *Geomorphology and Soils* (1985); *Slope Stability: Geotechnical Engineering and Geomorphology* (1987); *River Channels: Environment and Process* (1987); *Landform Monitoring, Modelling and Analysis* (1998); *Glacier Hydrology and Hydrochemistry* (1998); and themed issues of the *Philosophical Transactions, Royal Society Series A* (2004), *Geomorphology* (2007) and *Geoforum* (2007).

David Robinson graduated with a BSc in geography and a PhD in geomorphology from Kings College, University of London, before moving to Sussex where he is currently Reader in Physical Geography. He has researched and published extensively on rock weathering in a variety of environments, particularly in Europe and North Africa, on experimental weathering, and on the measurement of rock-surface change. He has a particular interest in sandstone weathering and the evolution of sandstone landscapes. More recently he has become heavily involved with European colleagues in studies of the weathering and erosion of rock coasts in macro-tidal, temperate environments. He is currently the Honorary Treasurer and serves on the Executive Committee of the British Society for Geomorphology.

André G. Roy is Professeur Titulaire at the Université de Montréal, where he also holds the Canada Research Chair in Fluvial Dynamics. He served as president of the *Canadian Geomorphological Research Group*, and of the *Canadian Association of Geographers*, and as Chair of the Grant Selection Committee of the Environmental Earth Sciences Committee of the *Natural Sciences and Engineering Research Council (Canada)*, and as Group Chair of the Earth Sciences Grant Selection Committees of NSERC. His research focuses on the study of flow turbulence and sediment transport in rivers and on the detailed quantification of fluvial processes. Recently he has worked on the response of rivers to environmental change. He has published more than 110 peer reviewed articles in a broad range of scientific journals in geomorphology, water resources and the earth sciences. He has received both national and international recognition for excellence in research and teaching, including the award for Scholarly Distinction from the Canadian Association of Geographers.

Mike J. Smith is currently a Senior Lecturer in GIS at the School of Geography, Geology and the Environment at Kingston University. He received a BSc (Hons) degree in geography from the University of Wales, Aberystwyth, an M.Sc. degree in geography from the University of British Columbia and a PhD degree in palaeo-glaciology from the University of Sheffield. Mike principally lectures to bachelor and masters' programmes on the application of remote sensing in the geosciences. His research interests are based around the application of digital elevation models in geomorphology and specifically focused upon the visualisation and gemorphometric modelling of glacial landscapes. Recent interests also include field spectroscopy of loess. He is the founder and Editor of the *Journal of Maps*.

László Sütő, was a PhD student of the Earth Sciences Doctoral School at the University of Debrecen, and has undertaken research on anthropogenic geomorphology and landscape evaluation for 10 years until 2007. He has been research fellow at interdisciplinary environmental projects of the Environmental Management and Law Association between 1998 and 2001. At present he is Senior Lecturer at the Institute of Tourism and Geography at College of Nyíregyháza. He is co-author of the book *Anthropogenic Geomorphology*, published by Springer Verlag in 2010, author of 52 articles, partly in Hungarian, partly in English on anthropogenic geomorphology, landscape evaluation, tourism and education in geography. He is a member of the Hungarian Geological Society and the Hungarian Geographical Society.

Graham Taylor has worked on regolith geology in Australia for the last 40 years, publishing more than 100 refereed papers in international journals and a book with Tony Eggleton. He has worked at ANU, HKU and the University of Canberra and continues in retirement to work on regolith, particularly bauxite.

Michael Thomas is Professor Emeritus in Environmental Science at the University of Stirling, Scotland. He holds degrees from Reading and London Universities and began his career in tropical geomorphology as a lecturer at the University of Ibadan in Nigeria from 1960–64, later based at St. Andrews and then Stirling, Scotland. Research into tropical weathering and geomorphology later branched out to include studies of Quaternary sedimentation and climate change. His book, *Geomorphology in the Tropics* (1994) continues to be a standard reference. His research was recognised by election to FRSE in 1988 and the award of the Centenary Medal (2000) of the RSGS and the David Linton Award (2001) of the BSG. He was Joint Editor of *Catena* 1996–2006.

Colin E. Thorn recently retired from the department of geography at the University of Illinois where he has spent thirty years as a geomorphologist, following brief spells at the Universities of Montana and Maryland in the same role. His research interests are focused upon periglacial and theoretical geomorphology. In the realm of periglacial geomorphology he has worked primarily in alpine contexts including the USA, Canada, Norway, Sweden and Finland. He has also worked briefly in a number of other periglacial contexts. His research on theoretical matters is centred primarily on the conceptual underpinnings of primary geomorphological principles.

Heather Viles is Professor of Biogeomorphology and Heritage Conservation at the University of Oxford. She grew up in Essex and studied at the Universities of Cambridge and Oxford before post-doctoral research at University College London on acid rain impacts on English cathedrals. Her research focuses on weathering of rocks in extreme environments (including on Mars) and the deterioration and conservation of building stones, with particular emphasis on the role of organisms. She is currently Vice-President (expeditions and fieldwork) of the Royal Geographical Society with IBG. Her most recent book, with Andrew Goudie, is *Landscape and Geomorphology* (2010).

Jeff Warburton is Reader in Geomorphology at Durham University. He completed his undergraduate studies at the University of Wales Aberystwyth before moving to the University of Colorado to carry out Masters Research. His PhD on glacio-fluvial sediment transfer was awarded by Southampton University prior to postdoctoral research in Natural Resource Engineering at Lincoln University in New Zealand. His research is concerned primarily with understanding the geomorphology and sediment transfer processes operating in upland and mountain catchments. Particular emphasis is placed on upland peat erosion, peat mass movements, debris flows/shallow landslides, glacio-fluvial sediment transfer and the geomorphology of mountain streams. This work is underpinned by intensive field monitoring programmes and geomorphological laboratory experiments. He also has a long-term interest in geocryology and the development of frost-sorted patterned ground.

Thad Wasklewicz is Associate Professor in the Department of Geography, East Carolina University. He received a PhD in geography from Arizona State University. His research interests include debris flow process-form interactions in alpine and arid settings of the western United States and Japan. The research has also expanded to encompass debris flow development after wildfires. Much of this work involves analyses of high-resolution digital terrain models developed from terrestrial laser scanning techniques.

Martin Williams is Emeritus Professor in Geographical and Environmental Studies, University of Adelaide, Australia. He holds a PhD degree from the Australian National University and a Doctor of Science (ScD) degree from the University of Cambridge. He has conducted extensive fieldwork in Africa, Australia, India and China, and is author of over 200 research papers on landscape evolution, climatic change and prehistoric environments in those regions. His two most recent books are *Quaternary Environments* (2nd ed., 1998) and *Interactions of Desertification and Climate* (1996).

Paul Williams was born in Bristol, England, and began caving in the nearby Mendip Hills as a schoolboy. He graduated BA Hons from Durham University and PhD and ScD from Cambridge University. He is a senior fellow of the International Association of Geomorphologists. He taught from 1964 at the University of Dublin (Trinity College) and later was a research fellow at the Australian National University, Canberra. He has been Professor at the University of Auckland (School of Environment) since 1972, where he supervised numerous PhD and Masters students. He has published on land use hydrology, coastal geomorphology and the Quaternary, although his chief area of research interest is karst, including landform evolution, hydrogeology, palaeoenvironmental studies of speleothems, and applied work. He has undertaken field research in New Zealand, Australia, Papua New Guinea, Niue, Ireland, France, USA, Vietnam, Russia and China. He is a member of the editorial boards of *Zeitschrift für Geomorphologie* and *Progress in Physical Geography* and a former member of the board of *Earth Surface Processes and Landforms*. He is a member of the World Commission on Protected Areas of IUCN and a member of their Caves and Karst Task Force. He has served on the executive of the International Association of

Geomorphologists and is currently a member of the executive (Bureau) of the International Speleological Union.

Colin Woodroffe is a coastal geomorphologist in the School of Earth and Environmental Sciences at the University of Wollongong. He has a PhD and ScD from the University of Cambridge, and was a lead author on the coastal chapter in the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment report. He has studied the stratigraphy and development of coasts in Australia and New Zealand, as well as islands in the West Indies, and Indian and Pacific Oceans. He has written a comprehensive book on *Coasts, form, process and evolution*, and recently co-authored a book on *The Coast of Australia*.

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1

Introduction to the Discipline of Geomorphology

Kenneth J. Gregory and Andrew Goudie

The word geomorphology, which means literally 'to write about (Greek *logos*) the shape or form (*morphe*) of the earth (*ge*)', first appeared in 1858 in the German literature (Laumann,1858; see Roglic, 1972, Tinkler,1985). The term was referred to in 1866 by Emmanuel de Margerie as 'la géomorpholgie'; it first appeared in English in 1888 (McGee, 1888a,b) and was used at the International Geological Congress in 1891 in papers by McGee and Powell. The term came into general use, including by the US Geological Survey, after about 1890, and it received wide currency in Mackinder's lecture to the British Association meeting in Ipswich in 1895 when he referred to 'what we now call geomorphology, the causal description of the earth's present relief' or the 'half artistic, half genetic consideration of the form of the lithosphere' (Mackinder, 1895: 367–379). The International Geographical Congress in London in 1895 had a section entitled Geomorphology, and A. Penck used the term in his paper to the meeting (Penck, 1895; Stoddart, 1986).

Although the late 19th century was when geomorphology was defined, the subject of study was recognizable much earlier (Tinkler, 1985) being significantly influenced by developments such as those in stratigraphy and uniformitarianism in geology and evolution in biology. Although there were many origins in geology, it became more geographically based with the contributions of W.M. Davis (1850–1934) who developed a normal cycle of erosion, suggested that it developed through stages of youth, maturity and old age, conceived other cycles including the arid, coastal and glacial cycles, and proposed that landscape was a function of structure, process and stage or time. His attractive ideas dominated geomorphology for the first half of the 20th century and arguably provided a foundation for later work and also encouraged debate by stimulating contrary views. Although alternative approaches, such as those by G.K.Gilbert, were firmly based upon the study of processes rather than on landform evolution, for the first half of the 20th century the influence of Davisian ideas ensured that geomorphology emphasized the historical development of landforms because the cycle of erosion introduced by Davis was appealing in its simplicity.

From its 19th century foundations geomorphology has developed enormously as reflected in the chapters in Section 1 of this book, including the history of geomorphology (Chapter 2), explanation (Chapter 3) and theory (Chapter 4), followed by geomorphology and environmental management (Chapter 5), and society (Chapter 6). This introduction focuses on the emergence and growth of the discipline, and then outlines the context of tensions, debates and issues that have arisen, many of which are elaborated in subsequent chapters.

EMERGENCE OF THE DISCIPLINE

It is possible to see how definitions of, or comments on, the scope of geomorphology (Table 1.1) reflect the way in which the discipline of geomorphology emerged and was established. Until 1900 many early definitions saw geomorphology as being concerned with description of the Earth's relief or with the form of the land (Table 1.1). However, according to Kirk Bryan (1941), Davis attempted to subdivide geomorphology as the genetic description of landforms into geomorphogeny, concerned with the history, development and changes of landforms, and geomorphography, concerned with their description. This distinction was not adopted (see Beckinsale and Chorley, 1991: 107) and indeed Davis preferred the term physiography, although he used the term geomorphology in an identical way. However, the distinction between the description of landforms and their development was identified by Russell (1949, 1958) who contrasted geographical with geological geomorphology (Table 1.1). In 1958 Russell commented that

> geomorphology has not developed as substantially as Gilbert forecast in 1890. Physiography concentrated on problems of erosion, almost to the exclusion

Table 1.1 Some definitions of geomorphology

Definition/quotation	*Source*
Qu'on peut appeler, a l'exemple de plusieurs savants américains, la géomorphologie'.	De Margerie, 1886, 315
Such genetic study of topographic forms (which has been denominated geomorphology) is specifically applicable in the investigation of the Cenozoic phenomena of the eastern United States.	McGee, 1888a, 547
These two ideas (drainage system and base level) gradually developed by a younger generation of students, are the fundamental principles of a new subscience of geology sometimes called geomorphology or physical geography.	Gilbert, 1902, 638
What we now call geomorphology, the causal description of the earth's present relief or the 'half artistic, half genetic consideration of the form of the lithosphere'.	Mackinder, 1895, 373
Die Geomorphologie.	Penck, 1895
Further illustration of the growing recognition of form as the chief object of the physiographic study of the lands is seen in the use of the term 'geomorphology' by some American writers.	Davis, 1900, 161
The geomorphologist may concern himself deeply with questions of structures, process and time, but the geographer wants specific information along the lines of what, where and how much.	Russell, 1949
Flood-plain deposits, deltas and deltaic plains are considered with reference to the sedimentary, structural and morphological processes under which they originated, as examples to illustrate the value of a more geological geomorphology.	Russell, 1958
To place geomorphology upon sound foundations for quantitative research into fundamental principles, it is proposed that geomorphic processes be treated as gravitational or molecular shear stresses acting upon elastic, plastic or fluid earth materials to produce the characteristic varieties of strain, or failure, that constitute weathering, erosion, transportation and deposition.	Strahler, 1952
Geomorphology is primarily concerned with the exogenous processes as they mould the surface of the earth, but the internal forces cannot be disregarded when one considers fundamental concepts of the origin and development of landforms.	Leopold, Wolman and Miller, 1964, 3
Whenever anyone mentions theory to a geomorphologist, he instinctively reaches for his soil auger.... Geomorphology is that science which has for its *objects* of study the geometrical features of the earth's terrain, an understanding of which has been attempted in the past within clearly definable, but not always clearly defined spatial and temporal scales and in terms of the processes which produced, sustain and transform them within those scales.	Chorley, 1978

Continued

Table 1.1 Cont'd

Definition/quotation	*Source*
Although the term is commonly restricted to those landforms that have developed at or above sea level, geomorphology includes all aspects of the interface between the solid earth, the hydrosphere and the atmosphere. Therefore not only are the landforms of the continents and their margins of concern but also the morphology of the sea floor. In addition the close look at the Moon, Mars and other planets, provided by space craft has created an extra-terrestrial aspect to geomorphology.	Chorley, Schumm and Sugden, 1984
Geomorphology may be defined as the science which studies the nature and history of landforms and the processes of weathering, erosion and deposition which created them. As such it has attracted, and overlapped with, the work of geologists, geographers, soil scientists and hydrologists.	Selby, 1985, 8
We see geomorphology as an holistic, chronological, integrative field-based science, that is integral to the study of a dynamically vibrant planet.	Baker and Twidale, 1991
Geomorphology is now a discipline that has major research frontiers ranging in scale from the transport paths of individual particles over a river bed to the combined tectonic and surface processes responsible for the 100 million year history of sub-continental scale landscapes.	Summerfield, 2005a
Geomorphology could...find itself at the centre of a group of new kinds of science, consistent with its traditional embracing of both geology and geography, the long term and the short, the global and the local, and using the tools of landscape-scale modelling to integrate both phenomena and scales.	Richards and Clifford, 2008

> of other parts of the discipline, and developed a terminology which became elaborated beyond usefulness. Disregard of the third dimension and inadequate geophysical backgrounds led to unrealistic results by physiographers.

Despite the approach of G.K.Gilbert, it was not until the mid 20th century that processes shaping the land and landforms gained prominence, as articulated by Strahler (1952) in dynamic geomorphology, and reinforced by Leopold, Wolman and Miller (1964) in their book *Fluvial Processes in Geomorphology*. These two contributions were outstanding stimuli for the instigation of process geomorphology. Strahler (1952) suggested that there were two quite different viewpoints of geomorphology, namely dynamic (analytical) and historical (regional) geomorphology which became associated with timeless and timebound perspectives. Also in the second half of the 20th century investigations into the Quaternary became more prominent. Whereas, previously, historical geomorphology had been focused on denudation chronology and especially on the morphogenesis of tertiary landscapes, investigation of contemporary glacial, deglacial and periglacial processes gave a significant stimulus to the investigation of Quaternary glacial systems, and this was further stimulated once investigations could be anchored to improved Quaternary dating using isotope stages.

A further strand was the inception of theory in geomorphology, crystallized by Chorley (1978), including his frequently cited comment that 'whenever anyone mentions theory to a geomorphologist, he instinctively reaches for his soil auger' (Table 1.1). Definitions used by two important texts in the 1980s reflected the multi-disciplinary nature of geomorphology (Selby, 1985) and the expanding horizons, to include non-terrestrial parts of the earth's surface and the potential inclusion of other planets (Chorley, Schumm and Sugden, 1984) (Table 1.1).

Although Baker and Twidale (1991) regretted the dominance of process geomorphology and pressed for a more holistic view (Table 1.1), further adjustment was achieved as a consequence of the advent of plate tectonics in the 1960s. Continental drift had long been acknowledged as a tectonic basis for geomorphology, and endogenic processes had been shown to be significant in studies over the past century (Haschenburger and Souch, 2004). However, the fundamental importance of plate tectonics was subsequently reinforced by geochronological techniques including cosmogenic dating methods. This reinvigorated geomorphology, so that Summerfield (2005a) saw two scales of geomorphology: small-scale process geomorphology contrasting with macroscale geomorphology reflecting advances made by researchers outside the traditional geomorphological community. However, Summerfield (2005a) sees the potential for links between these two groups of researchers, countering (Summerfield, 2005b) the view that the growing role of geophysicists could lead to a reduced role for geographical geomorphologists as visualized by Church (2005). Summerfield (2005b) believes that 'there is enormous scope to advance geomorphology as a whole probably at its most exciting time since it emerged as a discipline'. This has to cope with the advocation of earth system science (see Clifford and Richards, 2005) from which geomorphology could emerge at the centre of a group of new kinds of science (Richards and Clifford, 2008, see Table 1.1).

This therefore presents a paradox. On the one hand throughout the gradual emergence and broadening definition of geomorphology it is understandable why 'geomorphology is, and always has been, the most accessible earth science to the ordinary person: we see scenery as we sit, walk, ride or fly. It is part of our daily visual imagery ...' (Tinkler, 1985: 239). On the other hand, despite this accessibility and centrality, the discipline of geomorphology 'remains little known and little understood, certainly in relation to other academic disciplines, and especially outside university circles' (Tooth, 2009). Thus a discipline that should be very familiar is insufficiently known, although there is considerable potential to build upon the heritage and focus which differs from, and complements, other geosciences.

The discipline that emerged over more than a century, as expressed in the definitions and comments in Table 1.1, is now poised to develop further as a result of the techniques now available. Such emergence has effectively taken a century or so and during that time books published (Table 1.2) have reinforced the construction of the discipline, many aspects of which are discussed in a recent international encyclopedia of geomorphology (Goudie, 2004). Four substantial histories of the study of landforms have been published (Chorley et al., 1964, 1973; Beckinsale and Chorley, 1991; Burt et al., 2008) together with other perspectives including those of Davies (1968) and Tinkler (1985). Other books are referred to in Table 1.1 but particular ones collected in Table 1.2 exemplify seven themes. First were reactions to Davisian ideas: although credited with over 600 publications, Davis did not publish a book with geomorphology in the title so that *Geographical Essays* (1909) and his book in 1912 were his major works, and his ideas were conveyed in numerous articles. Although Davisian ideas were arguably the single most influential theory in geomorphology from the mid 20th century onwards (Tinkler, 1985: 147), they were challenged, amended and resisted by proffered alternatives (e.g. Hettner, 1921; Gregory, 2000). This second group included Penck's *Die Morphologische Analyse* published in 1924, a significant alternative to the Davisian approach to geomorphology which did not become widely known in the English-speaking world until it was available in translation in 1953 (Czech and Boswell, 1953). Third were textbooks necessary to establish the foundations, and books with geomorphology in the title included those by Wooldridge and Morgan (1937), Worcester (1939), Lobeck (1939), von Engeln (1942) and Thornbury (1954), although others that were influential had alternative titles such as *Physiography* (e.g. Salisbury, 1907). Whereas such texts endeavoured to present a perception of geomorphology as a whole, a fourth group offered a particular approach which may have been regional (e.g. Cotton, 1922), climatic (e.g. Tricart and Cailleux, 1955, 1965, 1972) or founded upon an alternative cyclic approach (e.g. King, 1962). A fifth group was made up of books which concentrated upon techniques (e.g. King, 1966) or upon processes (e.g. Ritter, 1978), whereas a sixth group comprises more recent texts (e.g. Chorley, Schumm and Sugden, 1984; Selby, 1985; Summerfield, 1991). In addition to these, a seventh group comprises those which cover the history of geomorphology (Chorley et al., 1964, 1973; Beckinsale and Chorley, 1991; Burt et al., 2008).

GROWTH OF THE DISCIPLINE

The growth of the present discipline over the last century was considerable, and is reflected in the creation of organized societies, the inauguration of journals and the proliferation of sub-branches of the subject.

Although geomorphology was represented in existing geographical and geological societies, a move towards its separate identification was exemplified by the creation of the Quaternary Geology and Geomorphology Division of the Geological Society of America in 1955 (Table 1.3), a division which has made very significant awards to recognize contributions made by distinguished geomorphologists. Inevitably individual countries created their own geomorphological societies, with the Swiss Geomorphological Society established in 1946 and succeeded by the British Geomorphological Research Group founded in 1959–1960. Such national societies engendered international contacts through their publications, often as collections of papers arising from meetings. It was from an international meeting organized by the British

Table 1.2 Some key publications establishing the subject, emphasizing books with geomorphology in their title

Date	*Author(s)*	*Title*
1909	Davis, W.M.	*Geographical Essays*
1912	Davis, W.M.	*Die Erklarende Beschreibung der Landformen*
1921	Hettner, A.	*Die oberflachenformen des Festlandes, ihre Untersuchung und Darstellung; Probleme und Methoden der Morphologie*
1922	Cotton, C.A.	*Geomorphology of New Zealand*
1924	Penck, W.	*Die Morphologische Analyse*
1937	Wooldridge, S.W. and Morgan, R.S.	*The Physical Basis of Geography: An outline of Geomorphology*
1939	Worcester, P.G.	*A Textbook of Geomorphology*
1939	Lobeck, A.K.	*Geomorphology: An Introduction to the Study of Landscapes*
1942	von Engeln, O.D.	*Geomorphology*
1953	Czech, H. and Boswell, K.C.	*Morphological Analysis of Landforms* (translation of Penck, 1924)
1954	Thornbury, W.D.	*Principles of Geomorphology*
1955	Tricart, J. and Cailleux, A.	*Introduction à la géomorphologie climatique*
1962	King, L.C.	*The Morphology of the Earth*
1964	Chorley, R.J., Dunn, A.J. and Beckinsale, R.P.	*The History of the Study of Landforms, Vol. I, Geomorphology before Davis*
1966	King, C.A.M.	*Techniques in Geomorphology*
1968	Davies, G.L.	*The Earth in Decay: A History of British Geomorphology 1578–1878*
1972	Tilley, P.	*The Surface Features of the Land* (translation of Hettner, 1928)
1973	Chorley, R.J., Beckinsale, R.P and Dunn, A.J.	*The History of the Study of Landforms, Vol. II, The Life and Work of William Morris Davis*
1978	Ritter, D.F.	*Process Geomorphology*
1984	Chorley, R.J., Schumm, S.A. and Sugden, D.A.	*Geomorphology*
1985	Tinkler, K.J.	*A Short History of Geomorphology*
1985	Selby, M.J.	*Earth's Changing Surface: An Introduction to Geomorphology*
1991	Beckinsale, R.P. and Chorley, R.J.	*The History of the Study of Landforms or The Development of Geomorphology, Vol. III: Historical and Regional Geomorphology 1890–1950*
1991	Summerfield, M.A.	*Global Geomorphology*
2008	Burt, T.P., Chorley, R.J., Brunsden, D., Cox, N.J. and Goudie, A.S.	*The History of the Study of Landforms or The Development of Geomorphology, Vol. IV: Quaternary and Recent Processes and Forms (1890–1965) and the Mid-Century Revolutions*

Geomorphological Research Group (now the British Society for Geomorphology) that the International Association of Geomorphology arose, (http://www.geomorph.org/main.html) now having successfully held congresses every 4 years in seven locations (Manchester, Frankfurt, Hamilton, Bologna, Tokyo, Zaragosa and Melbourne). Geomorphological societies have continued to be created and 22 are listed in Table 1.3.

Publication of research is essential for the growth of any discipline and, although in the first half of the 20th century many important geomorphological papers were published in geological and geographical journals, the growth of research activity and the increasing number of publications required establishment of dedicated geomorphological journals. A *Journal of Geomorphology* was inaugurated in 1938 but survived for just 4 years, probably affected by World War 2. Many journals were inaugurated due to the enthusiasm and vision of a single individual: Professor Jean Tricart was the inspiration for *Revue de Géomorphologie Dynamique* (1950–) and later the inception of *Earth Surface Processes* (1977–), which became *Earth Surface Processes and Landforms* in 1979, edited from its inception by Professor Mike Kirkby, under whose editorship it

Table 1.3 Examples of geomorphological societies

Society	*Date of foundation*	*Number of members*	*Objectives*	*Web site*
Swiss Geomorphological Society (SGS)	1946	200	Founded by a Geomorphological Working Group at the University of Basel	—
Quaternary Geology and Geomorphology Division of the Geological Society of America	1955		To bring together scientists interested in Quaternary geology and geomorphology, to facilitate presentation and discussion of their problems and ideas, to promote research and publication of results in those fields of geology	http://rock.geosociety.org/qgg/index.htm
British Geomorphological Research Group (BGRG)	1960		Established from a group focused on morphological mapping from 1958, first AGM of BGRG held in October 1960. Became BSG in 2006	—
Deutscher Arbeitkreis fuer Geomorphologie (German Geomorphologists Group)	1974		The professional organization for German Geomorphologists, organized within the German Association of Geography (DGfG)	http://gidimap.giub.uni-bonn.de:9080/geomorph/
Japanese Geomorphological Union	1979		Founded to expand interdisciplinary communication among sciences concerned with landform changes and related environmental aspects. Publishes *Transactions Japanese Geomorphological Union*	http://wwwsoc.nii.ac.jp/jgu/index.html
The Geomorphology Speciality Group (GSG)	1979	533	A component of the Association of American Geographers, to foster better communication among those working in the geomorphic sciences, especially geography. *Geomorphorum* is issued twice a year	—

Continued

Table 1.3 Cont'd

Society	*Date of foundation*	*Number of members*	*Objectives*	*Web site*
Australia New Zealand Geomorphology Group (ANZGG)	1982		Established primarily to organize conferences on geomorphic themes for the benefit of the community of geomorphologists in Australia and New Zealand	http://www.anzgg.org/
Sociedad Espanola de Geomorfologia (SEG), (Spanish Geomorphological Society)	1987	340	The development and promotion of geomorphology through cooperation and national and international exchange. Among its aims is the promotion and dissemination of knowledge of geomorphology, from different fields of knowledge such as geography, geology, engineering and biology and various fields of academia, government, business and industry. Edits the journal *Cuaternario & Geomorfología* in collaboration with the Spanish Association for Quaternary Studies (AEQUA) since 1987	http://www.geomorfologia.es/
Commission on Geomorphology of the Austrian Geographical Society (2000–)	1987		Informal grouping within the scope of the Vienna Institute for Geography; since 2000 is the Austrian Research Group Geomorphology and Environmental Change (Austrian Research Association on Geomorphology and Environmental Change) and also Austria	http://www.geomorph.at/
The Czech Association of Geomorphologists	1988	50	Founded as the Geomorphological Commission by the Physical Geography section of the Czech Geographical Society	http://www.kge.zcu.cz/geomorf/index.html
International Association of Geomorphologists	1989		IAG/AIG was founded at the Second International Conference on Geomorphology in Frankfurt/Main (Germany) in 1989 to strengthen international geomorphology. Principal objectives are development and promotion of geomorphology as a science through international cooperation and dissemination of knowledge of geomorphology	http://www.geomorph.org/main.html
Stowarzyszenie Geomorfologow Polskich (Association of Polish Geomorphologists)	1991	246	Dedicated to the advancement of the science of geomorphology as well as representative Polish geomorphologists in the country and abroad. Its primary activities are the publication of scientific literature, the organization of scientific	http://www.sgp.org.pl/

Continued

Table 1.3 Cont'd

Society	*Date of foundation*	*Number of members*	*Objectives*	*Web site*
			conferences, the creation of research grants, awarding of medals and awards, operation of task commissions, and other special activities like the protection of unique landforms. Headquarters office in Poznan	
Canadian Geomorphology Research Group (CGRG)	1993	250	To advance the science of geomorphology in Canada by (1) organizing and sponsoring technical sessions, workshops, and field trips; (2) publishing newsletters twice a year; (3) operating a listserver (CANGEORG) which maintains a comprehensive bibliography of Canadian geomorphological, Quaternary, and environmental geoscience publications; (4) supporting publication of technical reports and field guides; (5) presenting the J. Ross Mackay Award in recognition of a significant achievement by a young geomorphologist in Canada; and (6) cooperating with related earth science associations within Canada	http://cgrg.geog.uvic.ca/
Uniao da Geomorfologia Brasileira (UGB)	1996		Objectives are to (1) bring all those in Brazil or abroad to engage in Brazilian geomorphology and related fields; (2) promote the progress of Brazilian geomorphology; (3) encourage scientific and technological research related to the geomorphological context; (4) maintain exchange with professionals from related areas and national and foreign counterparts; (5) conduct regular meetings; (6) promote the expertise of scientists and technicians in various fields of geomorphology; (7) promote scientific and technical meetings that discuss matters of interest to the development of geomorphology; (8) disseminate technical and scientific information of interest to the policyholder; and (9) keep journals of members' work and news of interest to those involved in geomorphology in Brazil	http://www.ugb.org.br/home/?pg=1
Asociacia Slovenskych Geomorfologov (Association of Slovak geomorphology)	1996		A voluntary association of scientists and selection professionals in the field of geomorphology and its related disciplines. Based in Bratislava	http://www.asg.sav.sk/stanovy.htm

Continued

Table 1.3 Cont'd

Society	*Date of foundation*	*Number of members*	*Objectives*	*Web site*
Associazione Italiana di Geografia Fisica e Geomorfologia (Italian Association of Physical Geography and Geomorphology) (AIGeo)	2000		Established by the former National Group of Physical Geography and Geomorphology, for promoting, encouraging and coordinating research in the fields of physical geography and geomorphology. It also intends to promote educational ventures for physical geographers and geomorphologists and to facilitate the diffusion of environmental and territory knowledge	http://www.aigeo.it/
Associaçao Portuguesa de Geomorfólogos (Portuguese Association of Geomorphology) (APGeom)	2000		Dedicated to the interdisciplinary study and systematic forms of surface and the processes that create and transform. Founded to promote scientific knowledge in the context of geomorphology and its application in various areas of national interest	http://www.apgeom.pt/Apres/apres.htm
Mexican Society of Geomorphology (MSG)	2003		Involved in the organization of IAG Regional Geomorphology Conference, October–November 2003 in Mexico City	
British Society for Geomorphology (BSG)	2006		Professional organization for British geomorphologists, provides a community and services for those involved in teaching or research in geomorphology, both in the UK and overseas	http://www.geomorphology.org.uk/
Groupe Français de Géomorphologie (French Geomorphology Group) (GFG)			The GFG is an association (1901 Act) of people whose work directly or indirectly affects geomorphology. Geomorphology, as an environmental science, participates in the understanding and management of the environment and security of goods and people. Since 1995 GFG has published *Géomorphologie: Relief, Processus, Environnement*	http://www.gfg.cnrs.fr/spip.php?article18

Other organizations include The Geographical Society of China, Geomorfolosko drustvo Slovenije, The Southern African Association of Geomorphologists.

has become a leading international journal. Between these dates was the foundation of *Zeitschrift für Geomorphologie* (1956–) and *Geomorphological Abstracts* (1960–). By collecting together abstracts of papers published worldwide, *Geomorphological Abstracts* enabled wider knowledge of research outputs, catalysing greater dissemination and understanding of geomorphological activity. In 1989 the creation of the journal *Geomorphology* (Table 1.4) established an international serial that has become extremely important for the publication of research papers. Other journals listed in Table 1.4 are of three types: some are devoted to aspects of the earth's surface and its processes (e.g. hydrology, glacial and periglacial, coastal or arid environments, Quaternary morphogenesis); some are primarily geographical or geological but contain important geomorphology papers; and an environmental group emphasizes the fact that many papers now reflect research by multi-disciplinary teams of researchers.

As any discipline grows and expands it naturally fragments with the distinction of branches: such sub-divisions arise as groupings of active researchers, as a means of interfacing with other disciplines, providing communities which are easier to convene than those of the entire growing discipline, so that, naturally, publications tend to concentrate in certain disciplinary areas (e.g. journals included in Table 1.4). It is impossible to compile a list of all the branches of geomorphology that have been suggested but many of them are collected in Table 1.5: some are major branches with much activity and many adherents, such as fluvial geomorphology which attracted a large

Table 1.4 Examples of journals publishing papers on geomorphology (developed from Gregory, 2010)

Year initiated	*Journal*	*Comments*
1938	*Journal of Geomorphology*	Discontinued after several years of publication
1950	*Revue de Géomorphologie Dynamique*	Journal edited and inspired by Professor Jean Tricart
1956	*Zeitschrift für Geomorphologie*	Publishes papers from the entire field of geomorphological research, both applied and theoretical. Since 1960 has published 153 Supplementbände (Supplementary volumes) which cover specific important topics
1960	*Geomorphological Abstracts*	At first published abstracts of papers in geomorphology but later expanded to Geo Abstracts covering related disciplines
1977	*Earth Surface Processes and Landforms*	From 1977 to 1979 was *Earth Surface Processes* but then expanded its name. Described as an international journal of geomorphology publishing in all aspects of earth surface science
1989	*Geomorphology*	Publishes peer-reviewed works across the full spectrum of the discipline from fundamental theory and science to applied research of relevance to sustainable management of the environment
2002	*Journal of Geophysical Research – Earth Surface*	Focuses on the physical, chemical and biological processes that affect the form and function of the surface of the solid Earth
Hydrological		
1963	*Journal of Hydrology*	
1970	*Nordic Hydrology*	
1971	*Water, Air and Soil Pollution*	
1984	*Regulated Rivers*	
1987	*Hydrological Processes*	
Glacial and Periglacial		
1947	*Journal of Glaciology*	
1969	*Arctic and Alpine Research* (called *Arctic, Antarctic and Alpine Research* from 1999)	
1977	*Polar Geography and Geology*	
1980	*Annals of Glaciology*	

Continued

Table 1.4 Cont'd

Year initiated	*Journal*	*Comments*
1990	*Permafrost and Periglacial Processes*	
1990	*Polar and Glaciological Abstracts*	
Coastal		
1973	*Coastal Zone Management*	
1984	*Journal of Coastal Research*	
Arid		
1978	*Journal of Arid Environments*	
2009	*Aeolian Research*	
Quaternary		
1970	*Quaternary Research, Quaternary Newsletter*	
1972	*Boreas*	
1982	*Quaternary Science Reviews*	
1985	*Journal of Quaternary Science*	
1990	*Quaternary Perspectives, Quaternary International*	
1991	*The Holocene*	
Physical Geology		
1973	*Geology*	
1975	*Environmental Geology*	
Physical Geography		
1965	*Geografiska Annaler Series*	
1977	*Progress in Physical Geography*	
1980	*Physical Geography*	
Environment		
1972	*Science of the Total Environment*	
1973	*Catena*	
1976	*Geo Journal, Environmental Management*	
1990	*Global Environmental Change*	
1997	*Global Environmental Outlook*	

Geomorphological journals are followed by examples of other categories. Many geographical and geological journals such as *Geographical Journal* (1831–) and *Bulletin Geological Society of America* (1890–) contain important geomorphological papers.

proportion of geomorphological research activity. In Britain, whereas less than 20 per cent of publications were fluvial before 1960, this increased towards 30 per cent by 1975 (Gregory, 1978). The branches (Table 1.5) can be envisaged according to purpose, including quantitative research, which was much apparent after the 1960s during the quantitative revolution; applied research, which increased after the 1970s with the impact of the environmental revolution; and engineering geomorphology with a particular focus on applied aspects. A related group is defined according to analysis including process, climatic, historical, human activity or structural-based; the difficulty of recognizing separate fields is illustrated by the way in which karst geomorphology could relate to

Table 1.5 Some branches of geomorphology (developed from Gregory, 2009 in Gregory et al., 2009)

Branch of geomorphology	*Objective (links to other disciplines and sub-disciplines)*
According to purpose	
Quantitative	Use of quantitative, mathematical and statistical methods for the investigation of landforms, geomorphological processes and form process relationships requiring modelling.
Applied	Application of geomorphology to the solution of problems especially relating to resource development and mitigation of environmental hazards.
Engineering geomorphology	Provides a spatial context for explaining the nature and distribution of particular ground-related problems and resources, and also concerned with evaluating the implications of landform changes for society and the environment. The focus is particularly on the risks from surface processes (geohazards) and the effects of development on the environment, particularly the operation of surface processes and the resulting changes to landforms or the level of risks (see Fookes et al., 2005).
According to analysis	
Process	Exogenetic and endogenetic processes and the landforms produced.
Climatic	The way in which assemblages of process domains are associated with particular climatic zones. Sometimes extended with crude parameters to define morphoclimatic zones. Three levels of investigation recognized as:
	Dynamic – the investigation of processes (as above).
	Climatic – the way in which contemporary processes are associated with contemporary climatic zones.
	Climatogenetic – allowing for the fact that many landforms are the product of past climates and are not consistent with the climatic conditions under which they now occur.
Historical	Analysis of processes and landform evolution in past conditions. Sometimes referred to as palaeogeomorphology and interacting with fields such as palaeohydrology.
Structural/tectonic	Study of landforms resulting from the structures of the lithosphere and the associated processes of faulting, folding and warping.
Karst	The processes and landforms of limestone areas which have solution as a dominant process and give rise to distinctive suites of landforms. Special landforms and drainage above and below ground are due to solubility of calcareous rocks including limestone, marble and dolomite (carbonates), and gypsum, anhydrite and salt (evaporites) in natural waters. Derived from the geographical name of part of Slovenia.
Anthropogeomorphology	Study of human activity as a geomorphological agent.

Continued

Table 1.5 Cont'd

Branch of geomorphology	*Objective (links to other disciplines and sub-disciplines)*
According to process domains	
Aeolian	Wind-dominated processes in hot and cold deserts and other areas such as some coastal zones.
Coastal	Assemblage of processes and landforms that occur on coastal margins.
Fluvial	Investigates the fluvial system at a range of spatial scales from the basin to specific within-channel locations; at time scales ranging from processes during a single flow event to long-term Quaternary change; undertaking studies which involve explanation of the relations among physical flow properties, sediment transport and channel forms; of the changes that occur both within and between rivers. Results can contribute in the sustainable solution of river channel management problems.
Glacial	Concerned with landscapes occupied by glaciers, and with landscapes which have been glaciated because they were covered by glaciers in the past.
Periglacial	Non-glacial processes and features of cold climates, including freeze–thaw processes and frost action typical of the processes in the periglacial zone and in some cases the processes associated with permafrost, but also found in high altitude, alpine, areas of temperate regions.
Hillslope	The characteristic slope forms and the governing processes including processes of mass wasting.
Tropical	Processes, morphology and landscape development in tropical systems associated with chemical weathering, mass movement and surface water flow.
Urban	Processes and morphology in urban environments (urban hydrology, urban ecology).
Weathering	Processes involving the gradual breakdown and alteration of materials through a combination of physical, chemical and biological processes.
Soil geomorphology or pedogeomorphology	Attempts to describe and explain relationships between soils and landforms, including study of the evolution (temporal aspects) and distribution (spatial aspects) of soil and soil materials, and the landscapes in which they are formed and altered.
Mountain geomorphology	Dynamics of earth-surface processes and the formation of landforms in high mountains, with particular reference to the interactions between tectonics, climate, vegetation, hydrology and geomorphological processes.
Extra-terrestrial geomorphology	The origins of landforms and landscapes on planets other than Earth because geomorphological systems cannot be studied solely on the terrestrial land surface (see Baker, 2008).
Seafloor engineering geomorphology	As new mapping technology reveals that ocean floors exhibit a wide variety of relief, sediment properties and active geologic processes such as erosion, faulting, fluid expulsion and landslides, detailed surveys of sea floor geomorphology combine with other disciplines to contribute to solution of engineering problems (see Prior and Hooper, 1999).
Multi-disciplinary hybrids	
Hydrogeomorphology	The geomorphological study of water and its effects (fluvial geomorphology; geographical hydrology; hydrology).
Biogeomorphology	The influence of animals and plants on earth surface processes and landform development (ecology).

structural- or to process-based classification. A major grouping is based on particular processes or groups of processes, and includes the 13 categories in Table 1.5. A final grouping is of multi-disciplinary groups which include biogeomorphology and hydrogeomorphology, branches which have been established to foster links to research in other disciplines, in these two cases in ecology and hydrology.

Although it is now possible to visualize three broad types of approach, namely process, macro geomorphology and historical/Quaternary, many other sub-divisions of the subject continue and yet more are created such as ice sheet geomorphology (e.g. Fleisher et al., 2006) or seafloor geomorphology (Table 1.5). Such fragmentation of the discipline into many branches could dishearten the new student of the discipline but two implications arise. First, as this fragmentation has been characterized as investigating more and more about less and less, the so-called fissiparist or reductionist trend, there has been a growing awareness of the need to return to the 'big picture' with pleas for a more holistic view. In very general terms the first part of the 20th century saw the emergence of some branches of geomorphology, the second part of the 20th century witnessed the fissiparist creation of many more branches and sub-divisions, so that the 21st century has seen concerted efforts to realize a more holistic approach, a trend facilitated by new techniques available and required by the holistic nature of many problems demanding solution.

A second implication relates to how the chapters in this Handbook should be organized in view of the breadth and diversity of the branches available. If all branches of geomorphology were accorded a chapter, the volume could become too thick to hold together in one binding – perhaps a reason for the *Treatise of Geomorphology* being developed by Elsevier as an online publication. The method adopted here is to have an initial group of chapters dealing with foundation and relevance indicating how geomorphology developed (Chapter 2), evolved explanation (Chapter 3) and employed theory (Chapter 4) as well as demonstrating the relevance of environmental management (Chapter 5) and the importance to society (Chapter 6). In order to achieve the aims of the subject, approaches have included observations and experiments (Chapter 7), geomorphological mapping (Chapter 8), remote sensing (Chapter 12), geographical information systems (Chapter 13), and have required dating methods (Chapter 11). Many approaches are associated with processes and environments but some such as biogeomorphology (Chapter 14), human activity (Chapter 15) and extra-terrestrial geomorphology (Chapters 16 and 35) are clearly defined approaches which merit separate treatment. A major section of 13 chapters (Chapters 17–27) covers processes and environments, explaining how geomorphology has progressed through the investigation of specific groups of process assemblages and their impact on environments. A final group of chapters on environmental change shows how landscape evolution is now dependent upon our understanding of tectonics (Chapter 28), on how environments (Chapter 29) and environmental change can be interpreted (Chapter 30) and how approaches to landscape change and response can be visualized (Chapter 31). The conclusion includes short statements on challenges and perspectives from key leaders of several geomorphological organizations (Chapter 32) and a final chapter emphasizing the relevance of geomorphology to global climate change (Chapter 33).

THE CONTEXT OF DEBATES

As geomorphology has grown, accompanied by the profileration of sub-branches and ideas, it is inevitable that a number of tensions have arisen between the different branches, debates have ensued as a consequence, and discussion of certain issues has occurred, all conditioning the nature of geomorphology. Some individuals have been particularly influential, with Davis, Gilbert, Strahler and Chorley et al. recognized as fashion dudes (Sherman, 1996), and specific articles and books have been equally seminal: analysis of the references published in articles published in *Geomorphology* (1995–2004) showed that, of the 31,696 works cited, only 22 were referenced at least 20 times (Doyle and Julian, 2005). Debates are healthy drivers contributing to the progress of any discipline. A sequence of stages of development for remote sensing as suggested by Curran (1985, 6–7, following Jensen and Dahlberg (1983), was applied to physical geography (Gregory, 2000) and is tentatively adapted for geomorphology as shown in Table 1.6. The chapters of this Handbook amplify, illustrate and illuminate many of the discipline's debates but several are introduced here, not in order to steal the thunder of the subsequent chapters but to provide a context for those chapters.

Any discipline is limited in the subject matter that it can encompass and by its interfaces with other disciplines. So one debate concerns the *spatial limits of the discipline*, often referred to recently as the closure that restricts the spatial and temporal extent of the subject (Lane, 2000, 432). Analysis of the literature (e.g. Kondolf and Piegay,

Table 1.6 Discipline growth applied to geomorphology

Stage of growth of discipline (adapted after Jensen and Dahlberg, 1983)	*Application to geomorphology*
Preliminary growth period with small absolute increments of literature and little or no social organization	**Youth:** pre-1900, with origins in geology as well as in geography
	1900–1960: a period when geomorphology grew so that by the 1960s although some believed maturity to have been accomplished, the emphasis upon long-term landscape evolution meant that insufficient attention had been given to processes, to other branches of geomorphology and the relations of geomorphology to other disciplines
A period of exponential growth when the number of publications double at regular intervals and specialist research units are established	**Maturity:** 1960–2000, substantial growth achieved as illustrated by many new journals (Table 1.4) and books reflecting the branches of geomorphology (Table 1.5), with the influence of systems, models, quantitative and statistical methods and remote sensing
A subsequent period when the growth rate begins to decline and although annual increments remain constant, specialization and controversy increase	**Old age:** 2000– , growth rate may have declined but multi-disciplinary research has progressed involving geomorphologists, being exemplified by hybrid branches of the subject
A final period when the rate of growth approaches zero, specialist research units and social organization break down, and the subject reaches maturity	**Rejuvenation:** 2010– , a new phase where the role of geomorphology is redefined, enhanced by new techniques and potentially a more vibrant holistic and resilient discipline

2003; Doyle and Julian, 2005) can indicate the spread of geomorphological research activity, showing how geomorphology has come to be dominantly associated with the land surface of the Earth (Gregory, 2010), although it could encompass the sea floor, certainly in terms of seafloor engineering geomorphology (Prior and Hooper, 1999). A further extension can be in planetary terms because Baker (2008) has suggested that, to be a complete science of landforms and landscapes, geomorphology should not be restricted to the terrestrial portions of the Earth's surface because systems of landforms and their generative processes are best understood in a planetary context, so that to exclude extraterrestrial landscapes from geomorphology is illogical. If geomorphology includes planetary geomorphology as the study of the geomorphology of planets other than Earth then branches of geomorphology such as coastal can also be visualized in an extraterrestrial context (Parker and Currey, 2001).

Spatial limits are complemented by the debate about *temporal limits for geomorphology*. Indeed time pervades all fields of geomorphology (Thornes and Brunsden, 1977). Although prior to 1971 time had not been given explicit attention, a useful distinction between timebound (known periods of time) and timeless changes was highlighted by Chorley and Kennedy (1971: 251). Studies of change benefitted from the distinction between steady, graded and cyclic timescales suggested by Schumm and Lichty (1965), and by greatly refined Quaternary timescales, together with growing awareness that some land-forming events have occurred very rapidly. It is now accepted that geomorphological research is analogous to different levels of microscope magnification: some investigations relate to short periods of days or weeks; others may be concerned with change over hundreds or thousands of years; and yet others could be concerned with developments over millions of years. The concept of landscape evolution space has been introduced (Phillips, 2009a,b) as a tool for assessing landscapes and geomorphic systems, providing a systematic means for assessing the various factors that contribute to the potential for change in geomorphic systems (see also Chapter 33).

As geomorphological analysis can apply at a range of spatial and temporal scales, a further debate has concerned *relating space and time.* This has involved models of landscape evolution and change, consideration of themes such as thresholds and complex response (e.g. Schumm, 1979), coupled with the problem of transferring understanding from one timescale to another. Attempts to use spatial variations as a model for change over time periods, often referred to as space–time substitution or the ergodic hypothesis (e.g. Paine, 1985) have proved fruitful in certain situations and there is further scope for their development and also for relating ecological and geomorphological systems (Viles et al., 2008).

A further debate centres on *gradualism and catastrophism.* Whereas early interpretations saw many features of the Earth's surface as a consequence of catastrophic events, ideas developed during the 19th century gradually led to the notion that in uniformitarian terms the present was the key to the past with many processes and environments seen as the consequence of gradual and progressive change. However, geomorphological hazards and extreme events prompted the view that certain features of the Earth's surface can only be explained as a consequence of catastrophic events. Geomorphological systems cannot be explained entirely as the result of continuing processes, so that catastrophism has played a greater role than previously thought.

However, as discipline is limited, there are *contrasting approaches* with at least three alternative foci now perceived for geomorphology: (1) geographical, interpreting morphology and processes; (2) geophysical, concentrating upon the broad structural outlines (see Church, 2005; Summerfield, 2005b); and (3) chronological, focused on the history of change. A more evolutionary geomorphology involving global structural geomorphology can be seen as counteracting the emphasis placed upon the investigation of processes but may not always be clearly differentiated from the disciplines of geology and tectonics. Baker (1988) suggested that from 1888 to 1938, there were separate approaches, one grounded in geology, and a separate one with its roots in geography, but by the 1960s, geomorphology, led by fluvial studies, changed its emphasis from historical studies to process studies, so that the geology/geography dispute became irrelevant. The implications of plate tectonics for the earth's surface certainly produced a shift in the focus of geomorphology. A further recent approach is complexity which to some extent succeeds the realization that uncertainty exists in environmental systems meaning that it is easier to predict than to explain.

There has also been debate about the degree to which geomorphology should include consideration of *human impact*. Prior to the mid 20th century comparatively little geomorphological attention was given to human impact (though the work of Marsh, 1864, is a notable exception), but it was then increasingly recognized that it was impossible to investigate the surface of the Earth, and especially Earth surface processes, without reference to anthropogenic impact (see Gregory, 2000: Chapter 7; Goudie, 2005) and numerous implications are introduced in Chapter 15. However this can be extended further by considering whether geomorphology should include a greater cultural component. Just as a more society-oriented climatology or cultural climatology is envisioned so we can visualize a cultural geomorphology (e.g. Gregory, 2006). This does not detract from existing investigations of form, process and change but progresses by allowing for differences in human impact and legislative control according to culture and affecting future change.

To counter the increasingly specialized, fissiparist investigations, mentioned previously, the advantages of a more *holistic view* have become apparent. A holistic approach has arisen in at least two senses. First, within geomorphology, it has arisen to counter the greater specialist emphasis upon components of the land surface without sufficiently acknowledging the links between them. Thus linkages between components (e.g. Brierley et al., 2006) can emphasize ways in which nested hierarchical relationships between compartments in a catchment demonstrate both connectivity and disconnectivity in relation to geomorphic applications to environmental management. Second, as holism applies literally to the whole as more than the sum of the parts, it is the basis for greater links developed in multi-disciplinary investigations between geomorphology, and sub-disciplines of physical geography (e.g. Gregory et al., 2002), and also with other environmental and earth sciences such as the interface of geomorphology and ecosystems ecology (e.g. Renschler et al., 2007). Hybrid disciplines have been fostered, including ecogeomorphology and hydrogeomorphology, and multi-disciplinary investigations have been encouraged. Holistic approaches, countering the fissiparist trend which characterizes many of the sub-branches, have been in keeping with greater general awareness of environment, and hence with applications of geomorphology.

Potential *applications of geomorphology* have become more evident, with the ways in which applications may be communicated including applicable outputs embracing publications ranging from review papers, book chapters and books; and applied outputs which include interdisciplinary problem-solving, educational outreach, protocols and direct involvement (Gregory et al., 2008). Awareness of the potential effects of global warming becomes more urgent, with greater frequency of high magnitude events, possibly catastrophic ones, giving opportunities for geomorphic research as shown in the concluding chapter (Chapter 33), including investigation of potential implications of global change for coasts, flooding, glaciers and ground ice. There is also an increasing concern with other impacts of global change, such as deforestation, desertification and soil erosion (Slaymaker et al. 2009) and also with the geomorphological significance of hazards and disasters (Alcantara-Ayala and Goudie, 2010).

Emphasis upon process studies may have led to a relative neglect of landforms (Goudie, 2002), so that greater awareness of landforms (Gregory, 2010) and of visually attractive landscapes needs to be re-developed by geomorphologists, as an exemplar of proselytization of the discipline. The debate about whether *geomorphology is sufficiently visible* (Tooth, 2009) reminds us that there is a need not only for internal understanding but also of dissemination of the nature of the discipline and of the way in which the discipline can contribute in environmental problems. Subsequent chapters offer many examples of ways in which geomorphology is becoming increasingly relevant, although as the land surface is of increasingly wider interest its study may be subsumed within other disciplines. A recent report offering new horizons for research in Earth surface processes (NRC, 2009) identifies nine grand challenges and proposes four high-priority research initiatives (Table 1.7), which resound with the issues identified above and merit consideration against the background of the subsequent chapters.

The establishment of geomorphology (Table 1.7) might be thought of, slightly tongue in cheek, according to headings borrowed from Davis' geographical cycle of landscape development which dominated much of the early growth of the discipline. Using this interpretation the initial origins pre-1900, reminiscent of the way in which the cycle was associated with initial uplift, were followed by Youth up to 1960, and then by Maturity to at least 2000. However, is Old Age an appropriate appellation for the current state of the discipline? One possibility is that any symptoms of old

Table 1.7 Nine grand challenges and four high-priority research initiatives for research on earth surface processes as proposed by NRC (2009)

Challenges facing earth surface processes	*Comments*
What does our planet's past tell us about its future?	New tools and techniques to analyse the extensive natural record of Earth's landscape evolution will help scientists understand the processes that shaped Earth and predict how changing earth surface processes will shape the landscapes of the future.
How do geopatterns on the Earth's surface arise and what do they tell us about processes?	New observational tools and powerful ways to present spatial data, as in geographic information systems, can help scientists to understand how geopatterns form.
How do landscapes record climate and tectonics?	Some of the most intriguing research questions centre on the relative sensitivity and rates of the numerous feedback mechanisms among climate, topography, ecosystems, physical and chemical denudation, sedimentary deposition and the deformation of rocks in active mountain belts.
How do biogeochemical reactions at Earth's surface respond to and shape landscapes?	Chemical erosion and weathering of bedrock creates soil, essential for anchoring and nourishing life, and also contributes to landscape evolution and nutrient cycles.
What transport laws govern the evolution of the Earth's surface?	Mathematical laws to define fundamental rates of processes such as landslides, glacial erosion and chemical erosion are required to allow researchers to understand the mechanics and rate of landscape change.
How do ecosystems and landscapes co-evolve?	Understanding the linkages among living ecosystems, earth surface processes and landscapes, needed to fully understand Earth's changing surface.
What controls landscape resilience to change?	Changes under the influence of drivers such as climate, plate tectonics, volcanism and human activities – and when conditions change with sufficient magnitude and duration.

Continued

Table 1.7 Cont'd

Challenges facing earth surface processes	*Comments*
How will Earth's surface evolve in the Anthropocene?	Understanding, predicting and adapting to changing landscapes increasingly altered by humans is a pressing challenge which falls squarely within the purview of earth surface science. Research on the interactions between humans and landscapes needed to meet this challenge.
How can earth surface science contribute to a sustainable earth surface?	Some disrupted and degraded landscapes should be restored or redesigned.
Research initiatives	
Interacting landscapes and climate	Quantitative understanding of climatic controls on earth surface processes, and the influence of landscape on climate over time scales from individual storm events to the evolution of landscapes, will shed light on the connection between landscapes and climate.
Quantitative reconstruction of landscape dynamics across time scales	Developing detailed reconstructions of the evolution of Earth's surface, based on information recorded in landscapes and in sedimentary records, will provide information on how Earth's surface has changed over various time scales.
Co-evolution of ecosystems and landscapes	Forge a new understanding of the co-evolution of ecosystems and landscapes to address pressing problems of future environmental change.
Future of landscapes in the Anthropocene	How can we predict and respond to rapidly changing landscapes that are increasingly altered by humans?

age which appeared in the first decade of the 21st century are now poised to be followed by Rejuvenation, akin to the reasons for the instigation of a new cycle of erosion. Many of the subsequent chapters demonstrate how geomorphology is poised, after more than a century of development, to enter a new revitalized stage which characterizes a vibrant, holistic and resilient discipline. Readers can reach their own conclusions before this theme is returned to in the conclusion in Chapter 33.

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PART I

Foundation and Relevance

2

Geomorphology: Its Early History

Andrew Goudie

The subject matter of geomorphology – landscapes and the processes that mould them – has been something that has fascinated the human race for thousands of years (Goudie and Viles, 2010). Written documents relating to geomorphological knowledge developed during the European Renaissance, but much of this work was hugely influenced by biblical concerns, especially by the belief that Earth was created by Divine Intervention only 6000 years ago and had been moulded subsequently by catastrophes like Noah's flood (Bauer, 2004). The time span for geomorphological processes to operate and for forms to develop was very brief. However, towards the end of the 18th century ideas began to change (Chorley et al., 1964; Tinkler, 1985), notably in Edinburgh. James Hutton (1788), often seen as the founder (albeit unreadable) of modern geomorphology, his more lucid disciple, John Playfair (1802), and Charles Lyell (1830) argued for the importance of gradual subaerial denudation over millennia (Werritty, 1993). Gradualist and uniformitarian ideas took hold, and the concept that Earth was old and had a long history was appreciated. Additionally, the fluvialists argued for the dominance of rivers in denuding the landscape through slow, long-continued action (Kennedy, 2006). In effect, the real foundations of modern geomorphology were established in the early 19th century, although the term itself was not to be coined and adopted until decades later.

However, these radical ideas did not go unchallenged and the diluvialists, who included Buckland and Sedgwick, still pursued the view that catastrophic flooding had caused many surface features. There were also some structuralists who believed that valleys were essentially clefts or rents in the ground surface rather than the product of stream erosion as had been maintained by Playfair. Even Lyell argued that many phenomena, including erratic blocks in unexpected places, could be due to marine rather than sub-aerial action. However, a possible explanation for erratic blocks and other mysterious phenomena shortly became available – glacial agency.

THE GLACIAL THEORY

So, as we have seen, in the early years of the 19th century, the diluvial theory, which arose from a belief in the Biblical Flood (Noachian Deluge), was usually invoked to explain many geomorphological phenomena. However, in the 1820s and 1830s some scientists started to suggest that glaciers had once been much more extensive than today and could account for much of what was then called 'drift'. Notable was the work of Esmark in Norway, and Jean-Pierre Perraudin, Ignatz Venetz and Jean de Charpentier in the Alps (Wright, 1896; Imbrie and Imbrie, 1979; Teller, 1983). In Germany, Bernhardi (1832) proposed that glacier ice had once extended across Europe as far south as Germany.

The most famous exponent of the glacial theory was, however, Louis Agassiz. In 1836, following a tour around Switzerland with Venetz and de Charpentier, he became an enthusiast for the idea that in the past glaciers had been much more extensive than now. Agassiz developed this theory as his *Discours de Neuchâtel* (Agassiz, 1840). In 1840 he visited Scotland and recognized evidence for former glaciations. He managed to convert Oxford's William Buckland to the acceptance of his views, even though Buckland has been an arch diluvialist and ardent catastrophist (Oldroyd, 1999). Agassiz also visited Ireland and recognized the evidence for glaciations there (Davies, 1968).

The Glacial Theory was not well received by some members of the geological establishment in Britain, most notably Charles Lyell and Roderick Murchison, though the latter's opposition eventually thawed (Gilbert and Goudie, 1971). Lyell found that the glacial theory was incompatible with his uniformitarian ideas, as in a sense it was, and attributed many of the allegedly glacial phenomena to marine submergence and wave action (Dott, 1998). He formulated the theory that drift was the product of deposition by icebergs at times of high sea-level, and the presence of marine shells in some drift deposits at high elevations supported this notion. Even towards the end of the 19th century some opposition still remained. In 1893, for instance, H.H. Howorth produced his massive *neo-catastrophist The Glacial Nightmare and the Flood – a second appeal to common sense from the extravagance of some recent geology*, and tried to return to a fundamentalist–catastrophic interpretation of the evidence. Moreover, well into the 20th century British geomorphologists continued to argue that glaciers protected rather than eroded the landscape, with, for example, Gregory (1913) denying the role of glacier excavation in fjord formation. This chapter in the history of British glacier studies is well reviewed by Evans (2008).

The significance of the Ice Age beyond Europe was soon recognized. In New Zealand, F. von Hochstetter and J. von Haast were impressed by ancient moraines, lakes, fjords and the massive gravel plains of Canterbury (see Haast, 1879). Haast's work stimulated comparable researches in the Australian Alps by R. Von Lendenfeld (1886). In India, Sir Joseph Hooker remarked that he had met with ancient moraines in each valley he had ascended at about 7000–8000 feet (2134–2439 m) (Hooker, 1854: vol. ii, 103–4). Other observations from Kashmir and the Karakorams in the west to Sikkim in the east are described by Godwin-Austen (1864) and many subsequent workers.

Agassiz's views were adopted in the USA by Hitchcock (1841), who argued that the drift of Massachusetts was a glacial deposit. However, full appreciation of glaciation in North America partly resulted from Agassiz's visit in 1846 and it was Dana (1849) who was probably the first to suggest the former extensive glaciation of the Canadian Cordillera. During the 1850s and 1860s survey parties found evidence for a great Cordilleran Ice Sheet. More detailed investigations were carried out in the 1870s and 1880s by G.M. Dawson (1878) and T.C. Chamberlin (Jackson and Clague, 1991).

Various expeditions demonstrated that glaciers had formerly been more extensive in high mountains of lower latitudes as along the Andes of South America, the Atlas Mountains, Lebanon and the Caucasus and northern China (Geikie, 1874: 379). Finally, when J.W. Gregory ascended Mount Kenya (Gregory, 1894) he discovered abundant evidence that proved that glaciers had once extended over 1600 m below their present level.

A major development in glacial ideas occurred in the 1870s when it became recognized that there had been more than one glacial advance and that these had been separated by warm phases, called interglacials (Hamlin, 1982). People such as A. Geikie (1882, 1893) began to appreciate the complexity of drift stratigraphy in Scotland. In addition, Croll recognized that orbital fluctuations could have caused multiple alternations of glacial and interglacials (Croll, 1875). These trends led to the work by J. Geikie, who in *The Great Ice Age* (1874) appreciated the importance of interglacial periods. In its turn the work by the Geikies was extremely influential in the subsequent development of the classic and durable Penck and Brückner model of glacial chronology in the Alps (1909).

Scientists also started to be intrigued by other sorts of climatic change that might have occurred in non-glaciated regions. J.S. Newberry, who explored the Colorado Plateau in the 1850s, recognized these classic landscapes as having been 'formerly much better watered than they are today' (1861: 47). Lake basins, of the type that abound in the Basin and Range Province of the American West, with their spectacular abandoned shorelines, gave particularly clear evidence of hydrological change. Subsequently, other American scientists, like Gilbert and Russell, examined these same lake basins in greater depth. The travels of J.W. Gregory (1894) in the newly discovered East African rift valley revealed the former greater extent of many of the lakes that occurred within it. By World War 1 a picture was emerging of the scale of climatic change that had taken place in lower latitudes and of the very substantial alterations that had taken place in climatic belts as made evident not only by desiccated or shrunken lakes, but also by old river systems and ancient sand dunes (Penck, 1914).

RIVER VALLEYS AND THE POWER OF FLUVIAL DENUDATION

Although Hutton, Playfair and Lyell had made clear the role of rivers in landscape development, the acceptance of fluvialism was not a straightforward matter for, as Kennedy (2006, 4) pointed out, there were many phenomena that appeared to cast doubt upon whether valleys had actually been produced by rivers: the non-accordance of valley junctions (hanging valleys), especially in the Alps and other mountain ranges; the widespread occurrence of deep lakes in the upper courses of valleys which could not have been excavated by the 'normal' action of rivers; the existence of cases – such as those of the Cotswold Hills – where the stream was minuscule (misfit) compared with the size of the valley; the widespread occurrence of valleys with no streams in them at all (dry valleys); the existence of valleys – including the fjords of Scandinavia – which patently continued out under the sea; widespread deposits of non-local sands, gravels and erratic boulders – Buckland's Diluvium; and the fact that rivers sometimes ran into valleys which cut dramatically through high ground, as in the Weald of south-eastern England or in southern Ireland.

Related to the question of the origin of valleys was the question of the origin of planed off strata and of planation surfaces. In 1846, Ramsay had proposed that the roughly height-accordant summits of South Wales were a series of relicts that had been cut by wave action. Mackintosh argued (1869) that most facets of the British landscape, including escarpments (cliffs) and tors (stacks), had a marine origin.

In the 1860s, however, geomorphologists, as they soon came to be known, began to appreciate once again that rivers moulded valleys and were capable of achieving a great deal of geomorphological work and planation (Tinkler, 1985: 94 *et seq*.). There were various reasons for this. First, increasing acceptance of the power of former glaciers to cause wholesale transformation of the landscape and to produce features such as lake basins (Ramsay, 1862), explained away some drainage anomalies. Second, catastrophic/structural views on valley development were viewed with less favour. Third, when geomorphologists moved away from the relatively stable landscape of the British Isles to places like the Pacific islands, Assam or the mountains of Ethiopia, they encountered strong evidence of the power of rivers. Fourth, data on sediment loads of rivers demonstrated that they could indeed achieve a great deal of work. Fifth, some of the older and less progressive pioneers of the discipline were gradually passing from the scene (Davies, 1969: 317).

Croll (1875) made an early attempt to quantify rates of geomorphological change and used data on the amount of material being transported. Croll's fellow Scot, A. Geikie (1868), was equally concerned to demonstrate the power of sub-aerial erosion in comparison with that of the sea, and provided data on suspended loads for a range of the world's rivers, expressing them as a rate of surface lowering. The findings of Croll and Geikie were substantiated and strengthened by those of Ewing (1885) and Reade (1885).

Among the ardent fluvialists was Greenwood, who in 1857 produced *Rain and Rivers; or Hutton and Playfair against Lyell and all comers* (Stoddart, 1960). In it he championed the power of rainwash. More influential was Jukes (1862, 1866), who worked on the rivers of southern Ireland and showed that they had not only excavated their valleys but had also adjusted their courses to the underlying geological structures. Scrope (1866) was another exponent of fluvialism who pointed to the speed with which floods could transform landscapes.

A major figure in the revival of fluvialism (Chorley, et al., 1964: Chapter 20) was J.D. Dana (1850a, 1850b) who had travelled around the heavily dissected Pacific Islands. As Natland (1997, 326) wrote 'To become a fluvialist, all one has to do is ascend a large Tahitian Valley and get caught in a rainstorm'. One important convert to fluvialism was Ramsay, who as we saw earlier, had regarded the sea as the cause of planation in highland Wales. He recognized the role that rivers had played in developing the drainage of the Weald (Ramsay, 1872). The power of fluvialism, however, became sealed as a fundamental concept in geomorphology because of the impact that the landscapes of the American West, including the Grand Canyon, had on American geomorphologists such as J.W. Powell, C. Dutton, G.K. Gilbert and W.J. McGee (Orme, 2007a). Here there was abundant and dramatic evidence for the power of rivers. This, together with that from French hydraulic engineers, was used in France to good effect by La Noë and Margerie (see Broc, 1975). Their espousal of fluvialism transformed French geomorphology at the end of the 19th century. Another important figure in Europe was Rütimeyer (1869) who demonstrated that in the Alps valleys were not cracks in the crust but had been excavated by rivers.

ROCK DECAY

During the 19th century great strides were made in the understanding of physical, chemical and biological weathering processes, and these are well summarised by G.P. Merrill in his *A Treatise on Rocks, Rock-weathering and Soils* (1897) (Goudie and Viles, 2008). Knowledge of weathering phenomena owed a great deal to the growth of an independent science of pedology, or soil science, most notably by scholars like Dokuchayev (1883) in Russia.

The possible power of thermal fatigue weathering to cause rock disintegration was known to some early investigators. Merrill (1897: 180–3) summarises such views, which were adopted by many of the early desert geomorphologists such as Walther (1900), W. Penck (1924) and Hume (1925). Also in the early 19th century a great deal was learned about salt weathering because of its simulation in the laboratory as an analogue of frost weathering of building stones. Nineteenth century geologists were also well aware of the power of frost in producing angular debris (e.g. De la Beche, 1839) and recognized that one mechanism was the 9 percent volume expansion that accompanies the phase change of water to ice (e.g. Ansted, 1871).

With regard to chemical weathering, 19th century scientists carried out a wide range of chemical and mineralogical studies of weathering products and solutes, including laboratory simulations. There were also important studies of rates of chemical denudation, most notably by Bischof (1854). Various other studies hinted at the importance of organic acids to mineral decomposition (Goudie and Viles, 2008). Awareness of laterite, an enigmatic product of tropical weathering, goes back to Buchanan's work in south India in the early 1800s (see Goudie, 1973, for a discussion of early work on laterite and other duricrusts). By the end of the century laterite had also been recognized in the Seychelles, West Africa and Brazil (Prescott and Pendleton, 1952).

One particular aspect of weathering-related studies was the science of limestone (Karstic) relief and solution processes (see Rogliæ, 1972; Jakucs, 1977). Prime importance must be accorded to work on the Dinaric Karst and in particular to the extensive studies of one of A. Penck's students, Jovan Cvijić. His *Das Karstphänomen* (1893) and many subsequent works laid the theoretical foundations of many of our current ideas, though Serbian scholars had made some important studies before him (Ćalić, 2007).

MOUNTAIN BUILDING

During the 19th century there was considerable interest in how mountains formed (Adams, 1938) and in motions of Earth's crust (Chorley, 1963). E. Suess in Austria and Dana (1873) in the USA proposed that mountains formed through compressive stresses generated by a gradual thermal contraction of the whole earth (Oreskes, 1999: 10). Suess argued that, on a contracting Earth, mountains resulted from a wrinkling of the crust to accommodate a diminishing surface area. The belief in the power of secular cooling was something that had been promulgated earlier in the 19th century by geologists such as Eliede Beaumont (1852) and De La Beche (1834). Indeed the contraction theory was the dominant paradigm for most of the 19th century (Oldroyd, 1996: 171). Dana (1873) also believed in the secular cooling model, but believed that as Earth contracted its rocks would be squeezed to the greatest degree on continental margins. Dana developed his geosynclinal theory (Knopf, 1948) of sedimentary accumulation, compression and uplift. His idea that the earth's and ocean basins had always occupied the positions that they do now ('permanentism') came under attack in the early 20th century when ideas on continental drift appeared (Le Grand, 1988).

The contraction theory had its limitations, not least for explaining the shear amount of folding in the Alps and elsewhere as exemplified by nappe structures (Heim, 1878). It became evident that mountains were not always caused by vertical movements of the crust, as contraction theory tended to suggest, but by horizontal shortening (Penck, 1909). An opponent of the contraction theory was Fisher (1881), who proposed the idea of convection currents within Earth's interior. In addition, severe reservations with respect to the contraction theory arose because of the recognition of the importance of isostasy (Watts, 2001). Contractionism also suffered in the 1890s when radioactivity was discovered. Radioactive decay generated heat and this meant that Earth was not cooling down and contracting as rapidly as one in which the only heat source was its initial accretion (Rogers and Santosh, 2004: 4).

The importance of isostasy was also made evident by studies in formerly glaciated terrains which would have been affected by downwarping and upheaval in response to ice cap advance and recession respectively. This was the birth of the theory of glacio-isostasy (Jamieson, 1865, 1882). Jamieson's work was followed by that of De Geer (1888, 1892) in Fennoscandia. Early proponents of glacio-isostasy in America were Whittlesey (1868) and Shaler (a pupil of Agassiz) (1874). During his classic study of pluvial Lake Bonneville G.K. Gilbert (1890) found a dome-like pattern of uplift of former shorelines and inferred that this indicated hydro-isostatic recovery following the desiccation of the lake.

Building upon the work of people such as Dana and Fisher, and using his experience from the American West, where many mountains appeared to be composed of igneous rocks intruded into sedimentary sequences, Dutton, who invented the term 'isostasy' in 1882 (Orme, 2007a), argued that crustal deformation could be understood as a response to isostatic compensation (1889).

His model, in simple form, was that uplifted portions of the continent are eroded, that material is transported to coastal regions, that the weight of this material causes subsidence along the continental margins, which causes displacement of materials at depth, with this material moving laterally and producing igneous intrusions and further uplift of the continent (Orestes, 1999: Figure 2.5, p. 31). Gilbert (1890) built upon Dutton's ideas and noted that in the Basin and Range Province mountain building was associated with many faults and with crustal extension rather that crustal contraction (Haller, 1982). The significance of crustal tension was also recognized by Suess, as it was by Gregory (1894) who, working in the context of East Africa, was the first to use the term 'rift valley' (Dawson, 2008).

The hypothesis that mountain building could result from continental drift, though hinted at by Antonio Snider-Pellegrini in 1858 (Hallam, 1973: 1), was not developed in a concerted way until the early 20th century through the work of Taylor (1910) and Wegener (1912).

DAVIS AND THE CYCLE

William Morris Davis has been described as an Everest among geomorphologists (Chorley et al., 1973). He was the leading American geomorphologist of the late 19th and early 20th centuries. He spent most of his career at Harvard where he was an exacting but skilful teacher. Above all he was a very prolific author, writing more than 500 articles and books, many of them beautifully illustrated with his own line drawings.

His great contribution was to produce a deductive model of landscape evolution, called the Cycle of Erosion or the Geographical Cycle (Davis, 1899). This was developed during the 1880s and 1890s (Orme, 2004, 2007b) during a time when, following Darwin, evolutionary concepts were in vogue. His theory of landscape development was the dominant paradigm in American geomorphology from the late 19th to the mid-20th century (Sack, 1992). Davis believed that landscapes were the product of three factors: structure (geological setting, rock character, etc.), process (weathering, erosion, etc.) and time (stage) in an evolutionary sequence. Stage was what most interested him. He suggested that the starting point of the cycle was the uplift of a broadly, flat, low-lying surface. This is followed by a phase he termed *youth*, when streams become established and start to cut down and to develop networks. Much of the original flat surface remains. In the phase he termed *maturity* the valleys have widened so that the original flat surface has been largely eroded away and streams drain the entire landscape. The streams begin to meander across wide floodplains and the hillslopes become gradually less steep. In *old age* the landscape becomes so denuded that a low relief surface close to sea level develops, with only low hills (monadnocks) rising above it. This surface is then called a peneplain.

Initially, the Davisian model was postulated in the context of development under humid temperate ('normal') conditions, but it was then extended by Davis and successors to other environments, including arid, glacial, coastal, savanna, limestone and periglacial landscapes (Birot, 1968). His model was immensely influential and dominated much thinking in Anglo-Saxon geomorphology in the first half of the last century. The model was, however, largely deductive and theoretical and suffered from a rather vague understanding of surface processes, from a paucity of data on rates of operation of processes, from a neglect of climate change and from assumptions he made about the rates and occurrence of tectonic uplift. However, it was elegant, simple and tied in with broad, evolutionary concerns in science at the time.

In France the Davisian model was popularised by de Lapparent (1896) (see Giusti, 2004). Chorley et al. (1973) argued that Davis's cyclic model was not very successful in Germany, where it was opposed by such figures as Hettner and the Pencks (Tilley, 1968), though this may be something of an exaggeration (Wardenga, 2004). W. Penck's model of slope evolution (1924), often seen as the antithesis of Davis, involved more complex tectonic changes than that of Davis, and he regarded slopes as evolving in a different manner (slope replacement rather than slope decline) through time. An alternative model of slope development by parallel retreat leading to *pediplanation* was put forward by L.C. King in southern Africa. His model (1963) represents an amalgam of the views of Davis and Penck; episodic uplift resulting in both downwearing and backwearing, with the parallel retreat of slopes leading to the formation of low angle rock cut surfaces (pediments) which coalesced to form pediplains through the process of pediplanation. Thorn (1988) provides a useful comparative analysis of the Davis, Penck and King models of slope evolution (see also Chapter 4 in this Handbook).

By the mid 20th century the Davisian model was becoming less dominant and was the subject of a penetrating assault by Chorley (1965). This was partly because there was a growing awareness of crustal mobility that could not sustain notions of initial uplift followed by prolonged structural quiescence (Orme, 2007b).

DENUDATION CHRONOLOGY AND LONG-TERM EVOLUTION

The explanation of how landscapes came to attain their present form has always been a major objective of geomorphologists. Up to the 1960s, many workers adopted an historical approach to landscape evolution. Their aim was to identify the sequence of stages of erosional development that demonstrated how contemporary landscapes had been sculptured from hypothetical initial fairly uniform and featureless topographies. This sequential approach, with its focus on denudation, came to be known as 'denudation chronology' (Jones, 2004). During the first half of the 20th century, this became a major preoccupation of geomorphological studies in America, under the influence of D.W. Johnson, in Britain, where S.W. Wooldridge was a dominant figure, and in France, where H. Baulig's study of the Massif Central established a blueprint for subsequent work.

Classical denudation chronology sought to identify evidence of past planation surfaces and erosional levels in a landscape, in whatever way they formed, and to place them in a time sequence. To this end, two key concepts were employed. The first was that topographic 'flats', bevels and benches, together with accordant ridge and summit levels, represented the remnants of marine platforms, peneplains, pediplains produced during past periods of relatively stable base level. Often the studies that were undertaken focussed on a debate as to whether or not the identified erosional remnants were of sub-aerial or marine origin. A second concept was that there had been a progressive but episodic fall in base level through time, so that the most elevated features were the oldest. The resulting 'geomorphological staircases' often rose via terraces and benches to the more fragmentary remains of 'summit surfaces' preserved on ridges and escarpments. The identification and delimitation of such surfaces was usually based on visual observation, augmented by field mapping, profiling and various kinds of cartographic analysis, including the use of superimposed and projected profiles. Relatively little emphasis was placed on the study of surficial deposits.

Since the 1960s there has been less interest in classical denudation chronology. The 1960s witnessed the onset of radical changes to prevailing views of the past arising from growing knowledge about global tectonics and Quaternary climate change. Moreover, many geomorphologists concentrated on understanding the role of present day processes rather than trying to establish a long-term evolutionary history based on often small fragments of ancient landscapes preserved in the landscape at the present day.

CLIMATIC GEOMORPHOLOGY

In the 20th century, particularly in Germany and France, climatic geomorphology was a major approach. However, ideas about the importance of climate in determining processes and landforms germinated in the 19th century as more and more scientists carried out investigations outside Europe and more and more professional earth scientists became involved in scientific expeditions to areas that had previously been little known or had been impossible to access for logistical or political reasons. One strand of the development of climatic geomorphology was the study of periglacial and permafrost processes by European explorers of the vast sub-arctic regions of North America and Eurasia, though it was Lozinski who provided the first unifying concepts of periglacial geomorphology just before World War 1 (French, 2003). Other distinctive cold climate phenomena were also recognized. Nivation was a term introduced by Matthes (1900) to describe and explain the processes associated with late-lying seasonal snow patches and landforms derived from them (nivation benches and nivation hollows), while solifluction, the slow downslope movement of a saturated soil mass usually associated with freeze–thaw cycles and frost heave, was identified in the Falkland Islands by Andersson (1906).

Among the phenomena that scientists studied in lower latitudes were loess, desert dunes, desert weathering, coral reefs, deep weathering, laterites and inselbergs. Loess, a largely non-stratified and non-consolidated silt, containing some clay, sand and carbonate is a widespread and geomorphologically important deposit. During the 19th century many theories were advanced concerning its origin, including fluvial, marine, lacustrine and pedological ones. It is the subject of an enormous literature that developed after Lyell (1834) had drawn attention to the loamy deposits of the Rhine valley. It was, however, Von Richthofen (1882), working in China, who cogently argued that these intriguing deposits probably had an aeolian origin and were produced by dust storms transporting silts from deserts and depositing them on desert margins.

The colonization of the Sahara by the French from the 1880s onwards led to some of the first serious work on desert sand dunes (Goudie, 1999). However, dunes were not the only field of interest of desert travellers, for the exploration of deserts in the 19th century gradually led to the emergence of studies that established the nature of desert processes and their differences from those in other environments. French scientists were very active in the Western Sahara and accumulated a great deal of vital information on the full range of desert landforms (see Chudeau, 1909; Gautier, 1908).

Also notable was the work of Walther, who worked in the deserts of North Africa, Sinai the USA and Australia. His *Das Gesetz der Wüstenbildung in Gegenwart und Vorzeit* (1900) was the first full-scale book devoted to desert geomorphological processes and he championed the role of such mechanisms as thermal fatigue weathering, salt weathering and deflation.

American scientists also contributed greatly to the development of knowledge on desert landforms and processes (Udden, 1894; Free, 1911). Especially remarkable was the work of W.P. Blake on stone pavements, desert varnish, old lake basins, calcretes (caliche) and wind grooving of rock surfaces (e.g. Blake, 1855, 1904). It was also in the American West that W.J. McGee (1897) drew attention to the role of sheetfloods on pediment surfaces. Also notable were Gilbert's studies in the Colorado Plateau on rates of denudation in arid regions (Gilbert, 1876). The development of ideas on the role of wind in drylands is discussed by Goudie (2008a, 2008b).

THE TROPICS

During the voyage of the *Beagle* Charles Darwin saw many coral reefs. In 1842, he summarized his subsidence theory to explain the sequence of fringing reefs, barriers reefs and atolls (Spencer et al., 2008). As Davis (1913: 173) remarked:

> for forty years the scientific world accepted it as demonstrated. Darwin's diagram of a subsiding island and an up growing reef have been reproduced over and over again on countless blackboards, as representing one of the great discoveries of geological science.

Dana (1851, 1872) was a strong supporter of this theory and did much to make coral reefs a legitimate object of scientific enquiry in North America (Spencer et al., 2008: 870). The other key figure was Jukes (1847), but unlike Darwin and Dana he worked not on open-ocean atolls but on the Great Barrier Reef of Australia. However, like Dana, he wholeheartedly accepted Darwin's subsidence theory (Stoddart, 1988, 1989). Apart from coral reefs themselves, there was a recognition of some other features of lower latitude coastlines, including aeolianites (Rathbun, 1879; Branner, 1905) and beachrock (Beaufort, 1817; Darwin, 1841).

Geomorphologists gradually came to see the distinctive nature of humid tropical landforms and processes. Deep weathering was described from eastern China by Kingsmill (1864), and Russell (1889) appreciated the extent of deep weathering in the tropics in comparison with higher latitudes. However, the most important early paper on deep weathering was by Branner (1896) who stressed the importance of such factors as rank vegetation, termites, lichens, bacteria and lightning-generated nitric acid in assisting the role of tepid tropical rain. Pumpelly (1879) believed that the rock surface beneath the deeply weathered layer would be highly irregular and that if stripped off this uneven surface of weathering would be exposed. We have here the germs of an idea that developed in the 20th century to account for such phenomena as tors, inselbergs and etchplains (e.g. Falconer, 1911: Wayland, 1933; Büdel, 1957).

Passarge's work in the Kalahari (Passarge, 1904) had an influence in Davis's formulation of the arid cycle of erosion (Davis, 1905), while in Poland, Romer (1899) introduced the idea that the main morphological zones of Earth coincided with climatic zones and may have been affected by them (Kozarski, 1993: 348). The development of climatic geomorphology by A. Penck (1905) and von Richthofen in Germany and by E. de Martonne (1909) in France was facilitated and stimulated by the first global syntheses and classifications of soils (e.g. by Dokuchayev), plants (e.g. by Schimper) and climates (e.g. by Köppen). De Martonne's *Traité de Géographie Physique*, which was translated into English, Polish and Spanish 'directly or indirectly fuelled a full century of studies in physical geography across continental Europe' (Broc and Giusti, 2007).

In the USA, Davis recognized 'accidents', whereby non-temperate and non-humid climatic regions were seen as deviants from his normal cycle of erosion and he introduced, as we saw earlier, his arid cycle (Davis, 1905). Some (see Derbyshire, 1973) regard Davis as one of the founders of climatic geomorphology, although the leading French climatic geomorphologists, Tricart and Cailleux (1972), criticized Davis for his neglect of the climatic factor in landform development. Much important work was undertaken on dividing the world into morphoclimatic regions with distinctive landform assemblages in France (e.g. Birot, 1968), Germany (e.g. Büdel, 1982) and New Zealand (Cotton, 1942).

In the later years of the 20th century the popularity of climatic geomorphology became less as certain limitations became apparent (see Stoddart, 1969):

1. Much climatic geomorphology was based on inadequate knowledge of rates of processes and on inadequate measurement of process and form. Assumptions were made that, for example, rates of chemical weathering were high in the humid tropics and low in cold regions, whereas

subsequent empirical studies have shown that this is far from inevitable.

2. Some of the climatic parameters used for morphoclimatic regionalization (e.g. mean annual air temperature) were meaningless or crude from a process viewpoint. Macro-scale regionalization was seen as having little inherent merit and ceased to be a major goal of geographers, who eschewed 'placing lines that do not exist around areas that do not matter'.
3. Conversely, and paradoxically, climatic geomorphology had a tendency to concentrate on bizarre forms found in some 'extreme' environments rather than on the overall features of such areas.
4. Many landforms that were supposedly diagnostic of climate (e.g. pediments in arid regions or inselbergs in the tropics) are either very ancient relict features that are the product of a range of past climates or they have a form that gives an ambiguous guide to origin.
5. The impact of the large, frequent and abrupt climatic changes of the Late Cainozoic has disguised any simple climate–landform relationship. For this reason, Büdel (1982) attempted to explain landforms in terms of fossil as well as present day climatic influences. He recognized that landscape were composed of various 'relief generations' and saw the task of what he termed 'climato-genetic geomorphology' as being to recognize, order and distinguish these relief generations, so as to understand today's highly complex relief.

Although these tendencies have tended to reduce the relative importance of traditional climatic geomorphology, notable studies still appear that look at the nature of landforms and processes in different climatic settings (e.g. M. Thomas, 1994, and Wirthmann, 1999, on the humid tropics; D. Thomas, 1998, on dry lands and French, 1999, on periglacial regions).

G.K. GILBERT AND DYNAMIC EQUILIBRIUM

G.K. Gilbert was a remarkable American geomorphologist who, in many respects, was ahead of his time (Baker and Pyne, 1978). Although he died over 90 years ago, par excellence his career exemplifies many of the concerns of modern geomorphology. Working for much of his career in the American West, he made diverse and impressive contributions to the discipline. He helped to explain and name the structure and topography of the Basin and Range province with its many alternations of mountains and playas, he explained and classified the igneous intrusions that had created the Henry Mountains of the Colorado Plateau, he studied the greatest pluvial lake of the American West – Lake Bonneville – and recorded the evidence of its fluctuating levels, he established that large lakes could depress Earth's crust and so contributed to the growth of ideas about crustal mobility, and he helped to demonstrate that the craters on the Moon were the result of meteorite impact. However, the name of Gilbert is most often associated with that approach which is often termed dynamic geomorphology (see Chapter 3 in this Handbook).

This blossomed in the second half of the 20th century, and was defined by Strahler (1952) as an approach which treats geomorphic processes as 'gravitational or molecular shear stresses, acting on elastic, plastic or fluid earth materials to produce the characteristic varieties of strain or failure which we recognize as the processes of weathering, erosion, transportation and deposition'. As Slaymaker (2004: 307) remarked, 'the work of G.K.Gilbert is the first seminal antecedent of the study of geomorphic process or dynamic geomorphology'. This is exemplified in Gilbert's report on the *Geology of the Henry Mountains* (1877), his study of the convexity of hill tops (1909) and his work on the transportation of debris by running water (1914). Compared to Davis, Gilbert 'eschewed long-term cyclic interpretations in favour of an open-systems framework whereby landforms sought equilibrium shapes in response to changing fluxes of energy and mass' (Orme, 1989: 78).

In some areas of geomorphology, studies based on an analysis of force and resistance occurred earlier than in others (e.g. Terzaghi's work on slopes and rock mechanics in the 1920s; Bagnold's work on aeolian forms and processes in the 1930s; Hjulström's studies of processes in gravel rivers in the 1930s and the work of various physicists, such as Nye, Glen and Perutz, on glacier dynamics in the 1950s). Moreover, some geomorphologists, while they were great exponents of the Davisian model, were also greatly interested in processes. This is, for example, the case with D.W. Johnson's study of *Shore Processes and Shoreline Development* (1918).

CONCLUSION

The purpose of this chapter has been to present some of the main ideas that developed in geomorphology between the end of the 18th century and the second half of the 20th century. Among the