Orogenesis

The Making of Mountains

Orogenesis, the process of mountain building, occurs when two tectonic plates collide – either forcing material upwards to form mountain belts such as the Alps or Himalayas or causing one plate to be subducted below the other, resulting in volcanic mountain chains such as the Andes. The relatively recent discovery of plate tectonics gave us answers to questions such as why mountains are found in particular places on Earth, how long it takes them to form and what the limitations of their formation are.

Integrating the approaches of structural geology and metamorphism, this book provides an up-to-date overview of orogenic research, and an introduction to the physico-chemical properties of mountain belts. Global examples are explored, from the Scottish Caledonides, the Alps, the Andes and the Himalayas, and other chapters examine the deep structures and nature of mountain roots, with examples from Canada, Greenland and Antarctica. It includes a review of the role of the interactions of temperature and deformation in the orogenic process, and explains important new concepts such as channel flow.

This book provides a valuable introduction to this fast-moving field for advanced undergraduate and graduate students of structural geology, plate tectonics and geodynamics, and will also provide a vital overview of research for academics and researchers working in related fields including petrology, geochemistry and sedimentology.

Michael R. W. Johnson is a Fellow of the Royal Society of Edinburgh, and taught structural geology and tectonics in the University of Edinburgh for 40 years. He has undertaken research on orogenic belts in many parts of the world – Scotland, North America, the Alps and the Himalaya – and has continued his researches since his retirement in 1997. Dr Johnson has written over 80 papers, co-edited and contributed to several books, and organised and given key-note lectures at many international conferences. For many years he was on the editorial board of *Tectonophysics*, and has served on international committees such as the International Geological Correlation Programme (IGCP).

Simon L. Harley is Professor of Lower Crustal Processes at the School of Geosciences, University of Edinburgh. He has taught metamorphism and tectonics, Earth evolution, and aspects of isotope geology at the University of Edinburgh and Oxford University since 1983. He is recognised internationally as a world authority on metamorphism at extreme temperature conditions in the crust. He has undertaken field and laboratory-based research on several mountain belts, and has a particular interest in Antarctica, its evolution and environment. Professor Harley has written more than 100 papers, co-edited several conference proceedings and special volumes, and acted on the editorial boards of several key journals in geosciences, including *Geology* and the *Journal of Petrology*. He is a Fellow of the Royal Society of Edinburgh, and a recipient of the Imperial Polar Medal for contributions to Antarctic science.

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Contents

Preface

Mountains have attracted the attention of mankind at least since Rousseau (or did Petrarch precede him?*) who devoted much thought to nature, perhaps because the height and scale of mountains induced a sense of awe. A love of nature showed itself in the fairly recent desire to get to the top of mountains. George Mallory gave his reason for wanting to climb Everest as "because it is there", but long before that mountains were important for humankind, because they formed natural barriers for trade and the movement of armies. Perhaps the ancient Egyptians tried to simulate mountains in the pyramids of Giza. The same is true of builders of Gothic cathedrals, which were built ever higher so as to imitate mountains which reach up to heaven. The Greeks worshipped the gods on Mount Olympus, and mountains appeared often in Greek mythology; Prometheus, for example, was chained to a mountain side. The Greeks saw mountains as mysterious and frightening places, and even today for Hindus and Buddhists there are sacred mountains in the Himalaya such as Nanda Devi, Kailas and Everest – Qomolungma, the goddess mother of the Earth. Badrinath near the source of the Ganges in the High Himalaya is the home of the gods and a place of pilgrimage. Moses came down from a mountain bearing his famous tablets. Noah is supposed to have docked his ship on Mount Ararat. The Bible states "the mountains shall melt before the Lord" (Judges 5:5), but perhaps the reference was to volcanoes rather than orogenic mountains.

Many artists, too, have been fascinated by mountains. Leonardo Da Vinci realised that the fossils in the rocks of the Apennines showed that the rocks were once below sea level, and he and other painters used mountain scenes as backgrounds. Cezanne painted many pictures of Mont St. Victoire in Provence.

The word orogenesis means 'birth of mountains' (Greek, *oros*, a mountain and *genesis*, be produced, creation). From this we get orogen, which is a term for the characteristically long, narrow linear or curvilinear mountain belts, whether or not they have a marked topographic expression. So what is the definition of a mountain? In North America it is 600 m which seems very acceptable, but when we come to the definition of "high" mountains answers vary, from only a few hundred metres in Scandinavia, to 1660–1700 m in central Europe and 5500 m in central Asia. These numbers refer to the practice of defining mountains by reference to particular landscape features such as the tree line or snow line.

* We are grateful to Professor Usher of the University of Edinburgh who gave us the reference to Petrarch's *c.*1350 letter to his former confessor (Book 1V, Letter 1 of the *Familiares*). In this, Petrarch describes the ascent of Mont Ventoux in Provence, more a moral allegory than an ascent according to Usher. At the top he not only admired the view but read St Augustine's words, "Men go to admire the high mountains and the great flood of the seas and the wide-rolling rivers and the ring of the Ocean and the movement of the stars; and they forget themselves."

Our concern in this book is with the science of mountains and with the processes involved in their formation. Although the aim is not to give a comprehensive account of the orogens of the world, it is still necessary to present an account of the major features of selected orogenic belts. In Chapters 1, 2 and 3 we give brief elementary accounts of background material needed for the understanding of mountain building processes. Some readers may wish to skip these chapters or follow up the further reading given in the references.

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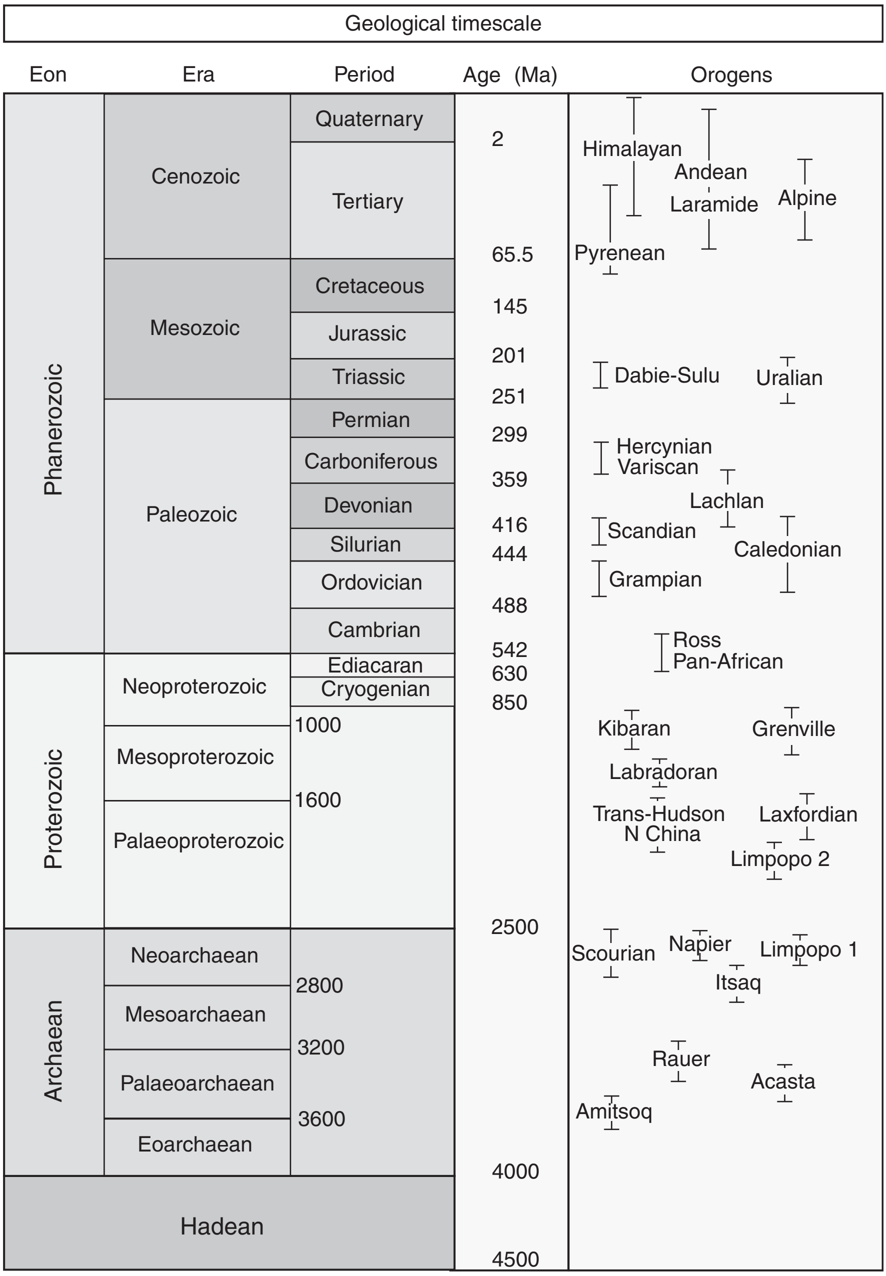
Geological timescale
Eon
Era
Period
Age (Ma)
Orogens
Phanerozoic
Proterozoic
Archaean
Hadean
Cenozoic
Mesozoic
Paleozoic
Neoproterozoic
Mesoproterozoic
Palaeoproterozoic
Neoarchaean
Mesoarchaean
Palaeoarchaean
Eoarchaean
Quaternary
Tertiary
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
Devonian
Silurian
Ordovician
Cambrian
Ediacaran
Cryogenian
1000
1600
2800
3200
3600
2
65.5
145
201
251
299
359
416
444
488
542
630
850
2500
4000
4500
Himalayan
Andean
Laramide
Alpine
Pyrenean
Dabie-Sulu
Uralian
Hercynian
Variscan
Lachlan
Scandian
Caledonian
Grampian
Ross
Pan-African
Kibaran
Grenville
Labradoran
Trans-Hudson
N China
Laxfordian
Limpopo 2
Scourian
Napier
Limpopo 1
Itsaq
Rauer
Acasta
Amitsoq