1 The Dynamic Earth

PROLOGUE 2
INTRODUCTION 3
HISTORICAL GEOLOGY AND THE FORMULATION OF
THEORIES 4
EARTH MATERIALS 4
The Rock Cycle 5
THE EARTH'S SURFACE AND INTERIOR 12
PLATE TECTONICS 14
The Rock Cycle and Plate Tectonics 16
FOSSILS AND EVOLUTION 16
THE GEOLOGIC TIME SCALE 17
CHAPTER SUMMARY 18

2 Geologic Time: Concepts and Principles

PROLOGUE INTRODUCTION EARLY DEVELOPMENT OF THE CONCEPT OF GEOLOGIC TIME 23 FUNDAMENTAL GEOLOGIC PRINCIPLES Steno's Principles 24 Perspective 2-1: Leonardo Da Vinci—Geologist ESTABLISHMENT OF GEOLOGY AS A SCIENCE—THE TRIUMPH OF UNIFORMITARIANISM OVER NEPTUNISM AND CATASTROPHISM 25 Neptunism and Catastrophism 25 Uniformitarianism 27 Modern View of Uniformitarianism LORD KELVIN AND A CRISIS IN GEOLOGY ABSOLUTE GEOLOGIC TIME 31 Atoms and Isotopes Radioactive Decay and Half-Lives 32 Potential Sources of Error 34 Long-Lived Radioactive Isotope Pairs 35 Dating by Fission Tracks Perspective 2-2: Fossils and the History of the Earth's Rotation 36 Radiocarbon and Tree-Ring Dating Methods CHAPTER SUMMARY

3 Rocks, Fossils, and Time

PROLOGUE 42
INTRODUCTION 43
STRATIGRAPHY 43
Vertical Stratigraphic Relationships 44
Lateral Relationships—Facies 48
Transgression and Regression 49
Extent, Rates, and Causes of Transgression and Regression 51
FOSSILS 51
Fossilization 52

Types of Preservation 54
Fossils and Uniformitarianism 58
Perspective 3-1: A Miocene Catastrophe in Nebraska 60
Perspective 3-2: The Irish Elk of Ballybetagh Bog,
Ireland 62
FOSSILS AND TIME 62
THE RELATIVE TIME SCALE 63
MODERN STRATIGRAPHIC TERMINOLOGY 66
CORRELATION 68
QUANTIFYING THE RELATIVE TIME SCALE 75
Dating Associated Igneous and Metamorphic Rocks 77
CHAPTER SUMMARY 78

4 Origin and Interpretation of Sedimentary Rocks

PROLOGUE INTRODUCTION 82 FEATURES OF SEDIMENTARY ROCKS Lithology 82 Fossils Sedimentary Structures and Paleocurrents Geometry 90 **DEPOSITIONAL ENVIRONMENTS** Continental Environments Transitional Environments Perspective 4-1: River-, Wave-, and Tide-dominated Deltas 96 Marine Environments 98 ENVIRONMENTAL INTERPRETATIONS AND HISTORICAL GEOLOGY 107 PALEOGEOGRAPHY AND PALEOCLIMATES CHAPTER SUMMARY

5 Evolution

PROLOGUE 112 INTRODUCTION 113 THE EVOLUTION OF AN IDEA Lamarck and the Giraffe's Neck 115 Charles Darwin's Contribution 115 Perspective 5-1: The Lysenko Affair 116 Natural Selection 117 MENDEL AND THE BIRTH OF GENETICS Genes and Chromosomes 119 THE MODERN SYNTHESIS Sources of Variation 120 Speciation and the Rate of Evolution 121 Divergent, Parallel, and Convergent Evolution 126 Evolutionary Trends 129 Perspective 5-2: Parallelism and Convergence of Saber-toothed Carnivorous Mammals Extinctions 131 EVIDENCE FOR EVOLUTION 133 Classification—A Nested Pattern of Similarities Biological Evidence for Evolution 135 Fossils and Evolution 137 Perspective 5-3: The Evolutionary Significance of Vestigial 140 Structures CHAPTER SUMMARY

6 Plate Tectonics—A Unifying Theory

PROLOGUE 144 INTRODUCTION 145 EARLY OPINIONS ABOUT CONTINENTAL DRIFT 146 Alfred Wegener and Continental Drift 146 Additional Support for Continental Drift 148 PALEOMAGNETISM AND POLAR WANDERING 149 MAGNETIC REVERSALS AND SEA-FLOOR SPREADING 151 PLATE TECTONICS AND PLATE BOUNDARIES Divergent Plate Boundaries 154 An Example of Ancient Rifting 156 Convergent Plate Boundaries 156 159 Ancient Convergent Plate Boundaries Transform-Fault Plate Boundaries 159 MANTLE PLUMES AND HOT SPOTS THE DRIVING MECHANISM OF PLATE Perspective 6-1: How Fast are the Plates Moving? 163 PLATE TECTONICS AND MOUNTAIN BUILDING 163 Perspective 6-2: Geosynclines and Plate Tectonics 164 PLATE TECTONICS AND EVOLUTION 166 CHAPTER SUMMARY 167

7 The Origin of the Universe, Solar System, and Planet Earth

175

175

178

PROLOGUE 170 INTRODUCTION 171 THE ORIGIN AND EARLY HISTORY OF THE UNIVERSE 174 THE CHANGING COMPOSITION OF THE UNIVERSE THE ORIGIN AND HISTORY OF THE SOLAR SYSTEM General Characteristics of the Solar System Evolutionary or Catastrophic Origin of the Solar System? Current Theory on the Origin and History of the Solar System 179 METEORITES—EXTRATERRESTRIAL VISITORS Stones, Irons, and Stony-Irons 181 Perspective 7-1: Meteorite Showers and Their Impact on Planets 182 METEORITES AND THE AGE OF THE EARTH 183 ORIGIN AND DIFFERENTIATION OF THE EARLY EARTH 186 Homogeneous Accretion 186 Inhomogeneous Accretion 188 Conclusions on Homogeneous versus Inhomogeneous Perspective 7-2: The Origin and Early History of the Moon 189 CHAPTER SUMMARY 191

8 Precambrian History—The Archean Eon

PROLOGUE 192
INTRODUCTION 193
PRE-ARCHEAN CRUSTAL EVOLUTION 195
SHIELDS AND CRATONS 198
Perspective 8-1: Archean Gold and the Battle of the Little Big
Horn 200

ARCHEAN ROCKS 201
Greenstone Belts 202
Greenstone Belt Evolution 205
DEVELOPMENT OF ARCHEAN CRATONS 208
ARCHEAN PLATE TECTONICS 211
THE ATMOSPHERE AND OCEANS 213
ARCHEAN LIFE 215
The Origin of Life 216
The Earliest Organisms 217
Perspective 8-2: Submarine Hydro-thermal Vents and the Origin of Life 218
CHAPTER SUMMARY 222

9 Precambrian History—The Proterozoic Eon

PROLOGUE 224 INTRODUCTION 226 PROTEROZOIC CRUSTAL EVOLUTION Hudsonian Orogeny 227 Colorado-Central Plains and Southern Provinces 229 Granite-Rhyolite Provinces 231 Grenville-Llano Orogeny Midcontinent Rift 233 PROTEROZOIC SUPERCONTINENTS PROTEROZOIC ROCKS Greenstone Belts 236 Quartzite-Carbonate-Shale Assemblages 236 Perspective 9-1: Ophiolites—Evidence for Ancient Convergent Plate Margins Glaciation and Glacial Deposits THE EVOLVING ATMOSPHERE Banded Iron Formations Red Beds 245 PROTEROZOIC LIFE 246 A New Type of Cell Appears Multicellular Organisms 249 Perspective 9-2: Symbiosis and the Origin of Eukaryotes 250 CHAPTER SUMMARY

Geology of the Early Paleozoic Era

PROLOGUE INTRODUCTION 257 THE CONTINENTAL FRAMEWORK Mobile Belts PALEOZOIC GLOBAL GEOGRAPHY Early Paleozoic Global History 261 EARLY PALEOZOIC EVOLUTION OF NORTH AMERICA 262 The North American Craton 263 THE SAUK SEQUENCE 263 A Transgressive-Regressive Facies Model: The Cambrian of the Grand Canyon Region 264 Perspective 10-1: Paleogeographic Reconstructions and Maps 265 THE TIPPECANOE SEQUENCE 266 Perspective 10-2: Pictured Rocks National Lakeshore Tippecanoe Reefs and Evaporites 268 General Characteristics of Modern Organic Reefs Silurian Organic Reefs and Evaporite Facies The End of the Tippecanoe Sequence

THE APPALACHIAN MOBILE BELT AND THE TACONIC OROGENY 274 CHAPTER SUMMARY 278

Geology of the Late Paleozoic Era

PROLOGUE 280

CHAPTER SUMMARY

PROLOGUE 308

INTRODUCTION 280 LATE PALEOZOIC GLOBAL GEOGRAPHY AND CLIMATE 280 The Devonian Period 280 The Carboniferous Period 283 The Permian Period 284 LATE PALEOZOIC HISTORY OF NORTH AMERICA 284 KASKASKIA SEQUENCE 284 Reef Development in Western Canada Perspective 11-1: The Canning Basin, Australia—A Devonian Great Barrier Reef 286 Black Shales 287 The Late Kaskaskia—A Return to Extensive Carbonate Deposition 288 ABSAROKA SEQUENCE 288 Cyclothems 288 Perspective 11-2: Brachiopod Migrations and Paleoclimatic Changes 293 The Late Absaroka—More Evaporite Deposits and Reefs HISTORY OF THE LATE PALEOZOIC MOBILE BELT CORDILLERAN MOBILE BELT 295 CRATONIC UPLIFT—THE ANCESTRAL ROCKIES OUACHITA MOBILE BELT 299 APPALACHIAN MOBILE BELT Caledonian Orogeny 301 Acadian Orogeny 301 The Old Red Sandstone Hercynian-Alleghenian Orogeny 303

Life of the Paleozoic Era

INTRODUCTION 309 THE FIRST SHELLED ANIMALS 310 THE CAMBRIAN PERIOD AND THE EMERGENCE OF A SHELLY FAUNA 310 THE ACQUISITION AND SIGNIFICANCE OF HARD PARTS 310 PALEOZOIC INVERTEBRATE MARINE LIFE The Present Marine Ecosystem Cambrian Marine Community The Burgess Shale Biota Ordovician Marine Community Silurian and Devonian Marine Communities Perspective 12-1: Extinctions: Cyclical or Random? Carboniferous and Permian Marine Communities The Permian Marine Invertebrate Extinction Event VERTEBRATE EVOLUTION

Perspective 12-2: The Discovery of the Oldest Complete Fossil Fish 331

AMPHIBIANS—THE VERTEBRATES INVADE THE

Perspective 12-3: Was There a Late Ordovician Invasion of the Land? 338

EVOLUTION OF THE REPTILES—THE LAND IS CONQUERED 338 PLANT EVOLUTION 343 Silurian and Devonian Floras 345 Perspective 12-4: The Oldest Amphibians in North America 346 Late Carboniferous and Permian Floras CHAPTER SUMMARY 352

Geology of the Mesozoic Era

PROLOGUE 356 INTRODUCTION 358 BREAKUP OF PANGAEA Evidence for Continental Breakup The Breakup of Pangaea 360 The Breakup of Pangaea and Its Effects on Global Climates and Ocean Circulation Patterns 363 THE MESOZOIC HISTORY OF NORTH AMERICA CONTINENTAL INTERIOR EASTERN COASTAL REGION **GULF COASTAL REGION** WESTERN REGION Triassic Tectonics 371 Triassic Sedimentation 373 Perspective 13-1: The Petrified Forest National Park Jurassic and Cretaceous Tectonics Jurassic and Cretaceous Sedimentation Perspective 13-2: Dinosaur National Monument MICROPLATES AND THE GROWTH OF WESTERN NORTH AMERICA 386 CHAPTER SUMMARY 388

Life of the Mesozoic Era

PROLOGUE 390 INTRODUCTION MARINE INVERTEBRATES FISHES AND AMPHIBIANS 395 PRIMARY PRODUCERS ON LAND—PLANTS 396 REPTILES 399 Thecodonts and the Ancestry of Dinosaurs 400 Dinosaurs 401 Flying Reptiles Perspective 14-1: The Largest Dinosaurs 410 Marine Reptiles 410 Crocodiles, Turtles, Lizards, and Snakes 413 Perspective 14-2: Sordes Pilosus—The Hairy Devil FROM REPTILE TO MAMMAL Therapsids and the Origin of Mammals MESOZOIC MAMMALS MESOZOIC CLIMATES AND PALEOGEOGRAPHY MASS EXTINCTIONS—A CRISIS IN THE HISTORY OF LIFE 422 CHAPTER SUMMARY

Cenozoic History—Tertiary Period

PROLOGUE 428 INTRODUCTION 429

CENOZOIC OROGENIC BELTS 432 Alpine-Himalayan Orogenic Belt 432 The Circum-Pacific Orogenic Belt 436 Perspective 15-1: The Perils of Living Near a Convergent Plate Margin THE NORTH AMERICAN CORDILLERA 443 Laramide Orogeny 444 Perspective 15-2: Intermontane Basin Deposition 448 Cordilleran Volcanism 449 Basin and Range Province Colorado Plateau 456 The Pacific Coast 458 THE INTERIOR LOWLANDS 460 **GULF COASTAL PLAIN** EASTERN NORTH AMERICA Cenozoic Evolution of the Appalachians 468 The Atlantic Coastal Plain CHAPTER SUMMARY

CENOZOIC PLATE TECTONICS—AN OVERVIEW

430

16 Life of the Tertiary Period

PROLOGUE INTRODUCTION 473 MARINE INVERTEBRATES AND PHYTOPLANKTON 476 TERTIARY BIRDS THE AGE OF MAMMALS BEGINS 477 PLACENTAL MAMMALS 478 **DIVERSIFICATION OF PLACENTAL MAMMALS** 479 Rodents, Rabbits, and Bats Primates Carnivores 483 Perspective 16-1: Condylarths Ungulates 488 Giant Mammals-Whales and Elephants TERTIARY VEGETATION AND CLIMATE 496 INTERCONTINENTAL MIGRATIONS Perspective 16-2: Fossil Forests—Yellowstone National Park 502 **CHAPTER SUMMARY** 504

Geology of the Quaternary Period and the Evolution of Humans

PROLOGUE 508 INTRODUCTION 509 The Onset of the Ice Age 510 PLEISTOCENE PALEOGEOGRAPHY AND CLIMATES 510 Paleogeography 510 Climate 512 PLEISTOCENE AND HOLOCENE CHRONOLOGY Stratigraphy of Terrestrial Sediments Pleistocene Deep-Sea Sediments Perspective 17-1: The Channeled Scablands of Eastern Washington—A Catastrophic Pleistocene Flood THE EFFECTS OF GLACIATION Continental Shelves and Submarine Canvons 522 Isostatic Rebound 523 Pluvial Lakes 523 History of the Great Lakes CAUSES OF PLEISTOCENE GLACIATION 525 Ice-Age Periodicity and the Milankovitch Theory Solar Variation, Volcanic Activity, and Third-Order Climatic Events 527 **HUMAN EVOLUTION** 529 THE PROSIMIANS 529 THE ANTHROPOIDS 529 The Australopithecines 531 The Human Lineage Neanderthals 538 Cro-Magnons Perspective 17-2: The Search for the Elusive Eve—A Controversial Theory Concerning the Origin of Humans 543 CHAPTER SUMMARY 545

Appendix A: English-Metric Conversion Chart 547

Appendix B: Classification of Organisms 549

Glossary 555

Index 565