

Earth System History

Steven Stanley's classic textbook, now co-authored with **John Luczaj**, remains the only book for the historical geology course written from a truly integrated earth systems perspective. The thoroughly updated new edition includes important new coverage on mass extinctions, climate change, and Proterozoic history, plus a range of interactive studying and teaching tools.

New to this edition

- Updated Organization – To better reflect the Geologic Time Scale, the book now covers the Neogene Age before the Quaternary Age.
- Updated Art Program – This edition's visual program offers over 100 new graphics and photos.
- Interactive Timeline of Earth and Life Through Time trace important aspects of Earth or its biota through its entire history and demonstrates how these topics are interrelated, underscoring important connections.
- Visual Overview Exercises provide students with a closer view of the chapter opening visual overviews, and ask related questions.

LaunchPad

Developed with extensive feedback from instructors and students, this new online course space offers:

- Pre-built units for each chapter, curated by experienced educators, with media organised and ready to assign or customise to suit your course.
- All resources for the text in one location, including an interactive e-book, LearningCurve adaptive quizzing, Case Studies, clicker questions, and more.
- Intuitive and useful analytics and gradebook that reveals how your class is doing individually and as a whole.
- A streamlined and intuitive interface that lets you create your entire course in minutes.

There is an option to purchase this book with LaunchPad. To find out more go to www.palgravehighered.com/launchpad



palgravehighered.com

Part I Materials, Processes, and Principles

CHAPTER 1

Earth as a System	1
Exploring the Earth System	2
Earth is a special planet	2
The components of the Earth system are interrelated	2
Aspects of the Earth system are fragile	2
The Principle of Actualism	3
Geologists conduct research based on actualism	3
Actualism replaced catastrophism in the nineteenth century	4
The Nature and Origin of Rocks	5
Igneous, sedimentary, and metamorphic rocks can form from one another	5
Bodies of rock are classified into formal units	8
Steno's three principles concern sedimentary rocks	9
The rock cycle relates all kinds of rocks to one another	9
Global Dating of the Rock Record	10
Fossils and physical markers indicate the relative ages of rocks	10
Radiometric dating provides actual ages of rocks	11
The geologic time scale divides Earth's history into formal units	11
Intervals of the geologic time scale are distinctive	12
Imaging Earth Below	13
Earth's density increases with depth	13
Solid, brittle plates of lithosphere move over the semisolid asthenosphere	14
Plate Tectonics	15
Plates spread apart where they form, slide past one another, and eventually sink	15
Heat from radioactive decay fires the engine of plate tectonics	17

Plumes of magma rise into the crust from deep within the mantle	17
Plate tectonics plays a role in the rock cycle	17
The Water Cycle	18
Water moves between reservoirs	18
The water cycle and the rock cycle are inseparable	19

Directional Change in Earth's History	19
Evolution reshapes life drastically and irreversibly	20
Physical and chemical features of Earth have also changed	20
Life and environments have changed in concert	20
Episodic Change in Earth's History	21
Sedimentation occurs in pulses	21
Deposition can be catastrophic	21
Unconformities represent large breaks in the rock record	22
Life on Earth has experienced pulses of change	22
Chapter Summary/Review Questions	23

CHAPTER 2

Rock-Forming Minerals and Rocks	25
The Structure of Minerals	28
An element consists of a unique kind of atom	28
Isotopes of an element have distinctive atomic weights	28
Chemical reactions produce minerals	29
Chemical reactions create chemical bonds	29
Crystals have three-dimensional molecular structures	31
Ions of an element can substitute for ions of another similar element	31
The Properties of Minerals	32
Chemical bonds determine hardness	32
The weight and packing of atoms determine density	32
Fracture patterns reflect crystal structure	32
Minerals and rocks form under particular physicochemical conditions	32

A few families of minerals form most rocks	35
Types of Rocks	35
Igneous rocks form when molten rock cools	35
Sedimentary rocks form from particles that settle through water or air	38
Metamorphic rocks form from other rocks at high temperatures and pressures	45
Chapter Summary/Review Questions	47

CHAPTER 3

The Diversity of Life 49

Fossils and Chemical Remains of Ancient Life 52

Hard parts are the most commonly preserved features of animals	52
Soft parts of animals are rarely preserved	52
Permineralization produces petrified wood	53
Molds and impressions are imprints	53
Trace fossils are records of movement	54
The quality of the fossil record is highly variable	54
Biomarkers are useful chemical indicators of life	54
Dead organisms decay to form fossil fuels	54

Taxonomic Groups 55

Identifying Clades and Their Relationships 57

Archaea and Bacteria: The Two Domains of Prokaryotes 61

Archaea can tolerate hostile environments	61
Bacteria include decomposers, photosynthesizers, causes of disease, and pollutants	61

The Protists: A Paraphyletic Group of Eukaryotes 62

Green Algae and Land Plants 64

Seedless vascular plants came first	66
Seed plants invaded dry land	66

Opisthokonts: Fungi and Animals 67

Fungi are decomposers	67
Animals are multicellular consumers	67
Sponges are simple invertebrates	67
Cnidarians include the corals	68
Lophotrochozoans include many kinds of animals that lack skeletons	69
Ecdysozoans have an external skeleton	71

The deuterostomes include invertebrates as well as vertebrates	73
--	----

Chapter Summary/Review Questions 77

CHAPTER 4

Environments and Life 79

Principles of Ecology 82

A species' niche is its position in the environment	83
A community of organisms and its environment form an ecosystem	83
Biogeography is the study of broad patterns of occurrence	85

The Atmosphere 85

Nitrogen, oxygen, and carbon dioxide constitute most of the atmosphere	85
Temperature variations and Earth's rotation govern circulation in the atmosphere	86

The Terrestrial Realm 88

Vegetation patterns parallel climatic zones	88
Climates change with elevation	91
Land and water influence seasonal temperature change	92
Fossil plants reflect ancient climatic conditions	94

The Marine Realm 95

Winds drive currents at the ocean's surface	95
Marine life varies with water depth	96
Marine life floats, swims, or occupies the seafloor	98
Water temperature influences biogeographic patterns	100
Salinity is an important limiting factor near shore	101

Freshwater Environments 101

Chapter Summary/Review Questions 102

CHAPTER 5

Sedimentary Environments 103

Nonmarine Environments 106

Ancient soils can point to past climatic conditions	106
Freshwater lakes and glaciers leave clues to ancient climates	107
Deserts and arid basins accumulate salt and sand	109

Braided and meandering rivers deposit sediment in moist regions	112
Marginal Marine and Open-Shelf Environments	114
A delta forms where a river meets the sea	114
Lagoons lie behind barrier islands of sand	117
Open-shelf deposits include tempestites	118
Fossils serve as indicators of marine environments	118
Organic reefs are bodies of carbonate rock	118
Carbonate platforms form in warm seas	121
Deep-Sea Environments	124
Turbidity currents flow down submarine slopes	124
Pelagic sediments are fine-grained and accumulate slowly	125
Chapter Summary/Review Questions	126

CHAPTER 6

Correlation and Dating of the Rock Record 129

The Geologic Time Scale 132

Fossil succession revealed the relative ages of rocks	132
Geologic systems were founded in the nineteenth century	133

Stratigraphic Units 134

The rock record is divided into time-rock units and geologic time into time units	134
Biostratigraphic units are based on fossil occurrences	134
Magnetic stratigraphy identifies polarity time-rock units	136
Rock units are defined by lithology, not age	136

Earth's Absolute Age 140

Early geologists underestimated Earth's antiquity	140
Radioactive decay provides absolute ages of rocks	141
Fossils often provide more accurate correlation than radiometric dating	144
Changes in stable isotopes permit global correlation	146

Event Stratigraphy 146

Marker beds allow correlation over wide areas	147
Back-and-forth shifting of facies boundaries creates a time line for correlation	148
Unconformities can be detected by seismic stratigraphy	148

Sequences record changes in sea level	150
Changes in Earth's rotation and the shape of its orbit create geologic clocks	151

Chapter Summary/Review Questions 153

CHAPTER 7

Evolution and the Fossil Record 155

Adaptations 158

Charles Darwin's Contribution 159

The voyage of the <i>Beagle</i> provided geographic evidence for evolution	159
Darwin's anatomical evidence for evolution was broadly based	161
Natural selection is the primary mechanism of evolution	162

Genes, DNA, and Chromosomes 162

Particulate inheritance is fundamental to genetics	162
Mutations provide raw material for natural selection	163
Genetic recombination also provides raw material for natural selection	163
Horizontal gene transfer is a novel mechanism of genetic change	164

Regulatory Genes and Patterns of Development 164

Populations, Species, and Speciation 164

Rates of Origination 165

Evolutionary radiations result from new ecological opportunities and adaptive breakthroughs	166
Rapid speciation can occur by way of small, isolated populations	168
A new higher taxon can arise through a single speciation event	171

The Molecular Clock and Times of Origination 171

Evolutionary Convergence 172

Extinction 173

Rates of extinction vary greatly	173
A mass extinction is occurring today	174

Evolutionary Trends 175

Animals tend to evolve toward larger body size	175
Evolutionary trends can be simple or complex	177
Evolution is irreversible	180

Chapter Summary/Review Questions 180

CHAPTER 8

The Theory of Plate Tectonics 183

The History of Continental Drift Theory 186

Some early observations were misinterpreted 186

Alfred Wegener was a twentieth-century pioneer 187

Alexander Du Toit focused on the Gondwana sequence 188

Continental drift was widely rejected 190

Paleomagnetism showed puzzling patterns 191

The Rise of Plate Tectonics 192

Seafloor spreading explained many phenomena 192

Paleomagnetism provided a definitive test 194

Faulting and Volcanism along Plate Boundaries 195

Oceanic crust forms along mid-ocean ridges 196

Transform faults offset mid-ocean ridges 196

Lithosphere is subducted along deep-sea trenches 197

Plate Movements 198

Plates move for four reasons 198

Free slabs sink deep into the mantle 199

Plate movements are measurable 199

Chapter Summary/Review Questions 201

CHAPTER 9

Continental Tectonics and Mountain Chains 203

The Rifting of Continents 206

Hot spots give rise to three-armed rifts 206

Rift valleys form when continental breakup begins 207

Rifting creates passive margins 209

Bending and Flowing of Rocks 209

Mountain Building 212

Continental collision produces orogenies 212

Orogenies can occur without continental collision 212

Mountain belts have a characteristic structure 213

Compressive forces cause deformation 213

The weight of a mountain belt creates a foreland basin 214

The Andes exemplify mountain building without continental collision 215

The Pyrenees exemplify mountain building by continental collision 217

Small landmasses may be sutured to continents 218

Tectonics of Continental Interiors 219

Chapter Summary/Review Questions 222

CHAPTER 10

Major Geochemical Cycles 223

Chemical Reservoirs 226

Fluxes are rates of movement between reservoirs 226

Feedbacks affect fluxes 226

Carbon Dioxide, Oxygen, and Biological Processes 227

Plants employ a photosynthesis-respiration cycle 227

Photosynthesis produces tissue growth 228

Respiration releases energy 228

Decomposers employ respiration 228

Burial of plant debris alters atmospheric chemistry 229

Marine photosynthesis-respiration cycles resemble those on land 231

Oxygen Isotopes, Climate, and the Water Cycle 231

Oxygen isotope ratios in skeletons reflect temperatures 232

Glaciers lock up oxygen 16 233

Oxygen isotope ratios vary with salinity 234

Water vapor acts as a greenhouse gas 235

Use of Carbon Isotopes to Study Global Chemical Cycles 235

Carbon isotope ratios record the cycling of organic carbon 235

Isotope ratios in limestones and deep-sea sediments record changes in rates of carbon burial 236

Carbon and sulfur burial enlarges the atmosphere's oxygen reservoir 236

Carbon dioxide is removed from the atmosphere by weathering and ends up in limestone 237

Changes in rates of weathering affect the atmospheric carbon reservoir 238

Changes in global temperature also affect the atmospheric carbon reservoir 240

Phanerozoic Trends in Atmospheric Carbon Dioxide 241

Positive feedbacks influence the carbon cycle	242
Negative feedbacks hold carbon dioxide levels in check	242
Carbon and Oxygen Isotope Excursions	243
Changes in respiration rates of bacteria influence carbon isotope ratios	243
Changes in the volume of methane hydrates influence carbon isotope ratios	244
Changes in phytoplankton productivity influence carbon isotope ratios	244
Episodes of massive carbon burial can override other factors that influence carbon isotope ratios	244
Ocean Chemistry and Skeletal Mineralogy	244
Variations in magnesium and calcium over time influence the production of marine carbonates	244
Variations in potassium and sulfate over time influence the mineralogy of evaporites	247
Organisms remove silica from the ocean	247
Chapter Summary/Review Questions	247

Part II The Story of Earth

CHAPTER 11

The Hadean and Archean Eons of Precambrian Time	249
The Ages of the Planets and the Universe	254
The Origin of the Solar System	255
The sun formed from a nebula	256
The planets formed from the solar nebula	256
The Hadean Eon	257
Early melting produced a layered Earth	258
The moon formed from a collision	258
The ocean's water came from volcanoes and comets, and its salts came from rocks	259
Earth's early atmosphere mostly came from within	259
Early Earth experienced many meteorite impacts	259
Early Earth was hot, and its plates were small	260
The Origin of Continental Crust	260
Felsic crust formed by melting of oceanic lithosphere	261
Continental crust appeared early in Earth's history	261

The Archean Eon	262
Archean continents remained small because of Earth's hot interior	262
The total amount of continental crust increased rapidly	262
Greenstone Belts	263
Earth System Shift 11-1 Large Cratons Appear near the End of Archean Time	264
Evidence of Archean Life	266
Chemical Evidence Bearing on the Origin of Life	268
Amino acids formed easily	269
Perhaps there was an RNA world	269
Life may have originated along mid-ocean ridges	269
Atmospheric Oxygen	272
Chapter Summary/Review Questions	272

CHAPTER 12

The Proterozoic Eon of Precambrian Time	275
A Modern Style of Orogeny	278
Global Events of the Paleoproterozoic and Mesoproterozoic	280
Glaciation was widespread early in Proterozoic time	280
Cyanobacteria flourished in the oceans, and eukaryotes joined them	281
The Beginnings of Animal Life	283
Animals burst on the scene	283
A buildup of atmospheric oxygen favored eukaryotes	287
Twice during Proterozoic time widespread glaciation extended to low latitudes	287
Earth System Shift 12-1 The Great Oxidation Event	288
Earth System Shift 12-2 Was There a Snowball Earth?	290
The diversification of animals may have changed the evolution of phytoplankton	292
The Expansion and Contraction of Continents	292
The Assembly of North America	293
Continental accretion expanded Laurentia during Proterozoic time	293
An extraterrestrial impact produced huge ore deposits	294
A rift formed in central and eastern North America	296

The Grenville Orogeny built mountains in eastern North America	297
The Assembly and Breakup of Neoproterozoic Supercontinents	297
The supercontinent Nuna contained all of Earth's large landmasses	297
The supercontinent Rodinia was smaller than Nuna	298
The supercontinent Pannotia, although it soon lost Laurentia, became part of Gondwanaland	299
Chapter Summary/Review Questions	299

CHAPTER 13

The Early Paleozoic World	301
The Cambrian Explosion of Life	304
The base of the Cambrian is defined by burrows of complex form	304
Many Early Cambrian groups evolved skeletons	304
Early Cambrian animals had few modes of life	307
Earth System Shift 13-1 <i>Skeletons Evolve in Many Animal Groups as Predators Diversify</i>	308
Later Cambrian diversification produced vertebrate animals	311
Ordovician Life	312
Among early Paleozoic animals were floaters and swimmers	313
A great radiation of life occurred later in the Ordovician	313
Animals caused stromatolites to decline	315
Extinction set back marine diversification	315
Invertebrates invaded fresh water and plants invaded land	316
Paleogeography of the Cambrian World	316
Episodic Mass Extinctions of Cambrian Trilobites	317
Ordovician Paleogeography, Climatic Change, and Mass Extinction	319
Climatic cooling brought about an ice age	319
Earth System Shift 13-2 <i>Climatic Cooling Results in Glaciation and Mass Extinction</i>	320
Climatic cooling also brought about a major mass extinction	322
Regional Events of Early Paleozoic Time	322
The Taconic orogeny raised mountains in eastern Laurentia	322
A passive margin persisted in western Laurentia	326

Chapter Summary/Review Questions	327
---	------------

CHAPTER 14

The Middle Paleozoic World	329
Renewed Diversification of Life	332
Life recovered and expanded in aquatic habitats	332
Plants invaded the land	338
Animals moved ashore	341
Earth System Shift 14-1 <i>Plants Alter Landscapes and Open the Way for Vertebrates to Conquer the Land</i>	342
The Paleogeography of the Middle Paleozoic World	345
Glaciation and a Mass Extinction	346
Regional Events of Middle Paleozoic Time	347
Eastern North America again became a passive margin	347
Earth System Shift 14-2 <i>The Expansion of Plants over Land Causes Global Climatic Change, Glaciation, and Mass Extinction</i>	348
Euramerica formed during the second Appalachian orogeny	350
Reef building and orogeny occurred in western North America	353
Chapter Summary/Review Questions	354

CHAPTER 15

The Late Paleozoic World	357
Late Paleozoic Life	360
New forms of life emerged in Paleozoic seas	361
Aragonitic reef builders flourished in aragonite seas	362
Trees grew in swamps	362
Upland floras expanded	365
Animals diversified on land and invaded freshwater habitats	366
Earth System Shift 15-1 <i>Weakened Greenhouse Warming Results in a Great Ice Age</i>	368
Paleogeography of the Late Paleozoic World	371
Warm, moist conditions were widespread in Early Carboniferous time	373
In mid-Carboniferous time, continents collided and a great ice age began	373
Dry habitats expanded in Permian time	374

Mass extinctions ended the Paleozoic Era	375
Earth System Shift 15-2 <i>The Most Destructive of All Mass Extinctions Ends the Paleozoic Era</i>	376
Regional Events of Late Paleozoic Time	379
The Alleghenian orogeny formed the Appalachian Mountains	379
Orogenies also occurred in the southwestern United States	381
Coal deposits formed within cyclothems	382
Reefs formed in the Delaware Basin of western Texas	384
The Sonoma orogeny expanded the North American continent	386
Chapter Summary/Review Questions	387

CHAPTER 16

The Early Mesozoic Era	389
Life in the Oceans: A New Biota	392
Three mass extinctions slowed the Early Triassic recovery	393
Pelagic life included new groups of phytoplankton and numerous swimming predators	394
Life on Land	398
Gymnosperms dominated the Mesozoic flora	398
The Age of Dinosaurs began	399
Earth System Shift 16-1 <i>The Rise of the Dinosaurs: Why Were They So Successful?</i>	401
Earth System Shift 16-2 <i>Volcanism and Mass Extinction</i>	408
A mass extinction ended the Triassic Period	411
The Paleogeography of the Early Mesozoic Era	411
The size of Pangaea affected climates and distributions of organisms	412
Pangaea began to fragment	412
Tropical and nontropical zones were evident	413
Tectonic Events in North America	414
Fault block basins formed in the east	414
North America grew westward	415
Chapter Summary/Review Questions	419

CHAPTER 17

The Cretaceous World	421
Cretaceous Life	424
Pelagic life was modernized	424

Benthic life was also modernized	426
Flowering plants expanded on land	428
Dinosaurs dwarfed early mammals	429
Paleogeography of the Cretaceous World	433
Continents fragmented and narrow oceans expanded	433
Sea level rose, the deep ocean stagnated, and climates warmed	433
The Terminal Cretaceous Extinction	437
The terminal Cretaceous impact serves as a warning	438
Fossils disguised the timing of the extinction	438
Opportunistic species flourished in the aftermath of the extinction	438
North America in the Cretaceous World	439
Cordilleran mountain building continued	439
Earth System Shift 17-1 <i>Death from Outer Space</i>	440
A seaway connected the Gulf of Mexico and the Arctic Ocean	444
An ancient river excavated the chasm that became the Grand Canyon	445
The modern continental shelf formed in eastern North America	446
The Chalk Seas of Europe	447
Chapter Summary/Review Questions	448

CHAPTER 18

The Paleogene World	449
Life of the Paleogene	452
Marine life recovered	452
Flowering plants rose to dominance	454
Mammals radiated dramatically in the Paleocene and Eocene	454
Early Paleogene birds were large	457
Modern groups of hoofed animals, carnivores, and primates expanded in the Oligocene	458
Frogs and insects were modernized in Paleogene time	460
Paleogene Climates	460
The Eocene began with a pulse of warming	460
Warmth extended to high latitudes	462
Cooling and high-latitude glaciation began in the Middle Eocene	464
Climatic change, glacial expansion, and a mass extinction marked the Eocene-Oligocene transition	464
Regional Events of Paleogene Time	465

Positions of land and sea changed near the poles	465
Mountain building continued in western North America	465
Earth System Shift 18-1 <i>Global Cooling and Drying Begins</i>	466
A rift developed in the American Southwest	471
Shallow subduction produced volcanism in the Yellowstone region	471
Deposition continued along the Gulf Coast	472
A meteorite created the site of the Chesapeake Bay	473
Chapter Summary/Review Questions	475

CHAPTER 19

The Late Cenozoic World Before the Holocene

Life of the Neogene Period	480
In the ocean, whales radiated and foraminifera recovered	480
On land, species adapted to seasonally dry habitats flourished	481

The Modern Ice Age of the Northern Hemisphere

Early Pliocene climates were relatively warm	485
Continental glaciers formed in the Northern Hemisphere	485
The chronology of glaciation can be read in isotope ratios	487
Climatic changes altered floras	488
Glaciers expanded and contracted many times	489

Earth System Shift 19-1 *Shockingly Rapid Climatic Shifts Occur during the Ice Age*

Vegetation patterns changed during glacial maxima	492
Changes in oceanic circulation may have triggered the ice age	493
Changes in Earth's rotational movement have affected glacial cycles	494
Changes in the greenhouse effect resulted from climatic oscillations	494

Regional Events of Neogene Time

Mountains rose up throughout the American West	495
The Appalachians bobbed up and shed sediment eastward	503
The Caribbean Sea was born	504
North and South America exchanged mammals	505

The Himalaya rose to become Earth's highest mountain range	506
--	-----

The Tethys Seaway came to an end	508
----------------------------------	-----

Human Evolution

Early apes radiated in Africa and Asia	509
The earliest hominid lived about 6 million years ago	509
The australopithecines resembled both apes and humans	509
The human genus made a sudden appearance	511
<i>Homo erectus</i> resembled us	513

Earth System Shift 19-2 *The Human Genus Arises at a Time of Sudden Climatic Change*

The Flores people were curious dwarfs	516
<i>Homo heidelbergensis</i> was more similar to us than <i>Homo erectus</i>	516
The Neanderthals emerged in Eurasia	517
<i>Homo sapiens</i> evolved in Africa and spread north	518

Chapter Summary/Review Questions

CHAPTER 20

The Retreat of Glaciers and the Holocene

The Retreat of Glaciers	525
Abrupt Global Events of the Latest Pleistocene and Early Holocene	526
The Younger Dryas	526

Earth System Shift 20-1 *Evidence That a Comet Struck Earth, Causing the Younger Dryas Event, the Extinction of Large Mammals, and the Disappearance of the Clovis Culture*

The First Americans	531
A Sudden Extinction of Large Mammals	532
Climatic Fluctuations of the Last 10,000 Years	533

The hypsithermal interval was a brief period of global warmth	534
Humans invented agriculture	534
Glaciers, tree lines, and tree rings record climatic change	535
Temperatures have fluctuated since the hypsithermal interval	536
Severe droughts have occurred during Holocene time	536

Sea Level Changes

Sea level rose rapidly in the early Holocene	538
--	-----

Coastlines have shifted during the past 7000 years	538	Sea level is rising	543
The Twentieth and Twenty-First Centuries: The Impact of Humans	540	Positive feedbacks may speed climatic change	545
Anthropogenic gases in the atmosphere are causing greenhouse warming	540	Chapter Summary/Review Questions	546
Future climatic change will have serious consequences	541	<i>Appendix: Stratigraphic Stages</i>	549
Increased carbon dioxide concentrations in the oceans are inhibiting calcification by marine organisms	543	<i>Glossary</i>	553
		<i>Index</i>	569