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4th Edition

Investigating OCEANOGRAPHY

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Keith A. Sverdrup • Raphael M. Kudela



Fourth Edition

INVESTIGATING OCEANOGRAPHY

Keith A. Sverdrup

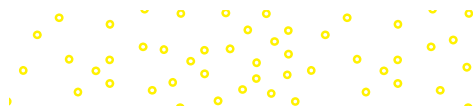
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INVESTIGATING OCEANOGRAPHY

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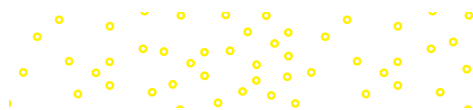
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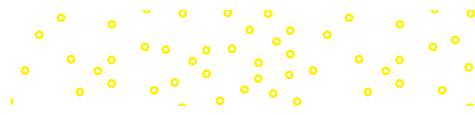
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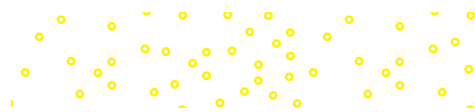


Dedicated to

Barbara Sverdrup Stone and
Stephanie Fouse

and

Robert, Eleanor, and Sarah Kudela



About the Authors



Courtesy of Barbara Sverdrup Stone

Keith A. Sverdrup is Emeritus Professor of Geophysics at the University of Wisconsin-Milwaukee (UWM), where he taught oceanography for over thirty-five years and conducted research in tectonics and seismology. He is a recipient of UWM's Undergraduate Teaching Award and is a Fellow of the Geological Society of America.

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Courtesy of Sarah Kudela

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Brief Contents

PROLOGUE

The History of Oceanography 3

CHAPTER **1**
The Water Planet 35

CHAPTER **2**
Earth Structure and Plate Tectonics 59

CHAPTER **3**
The Sea Floor and Its Sediments 91

CHAPTER **4**
The Physical Properties of Water 121

CHAPTER **5**
The Chemistry of Seawater 141

CHAPTER **6**
The Atmosphere and the Oceans 161

CHAPTER **7**
Ocean Structure and Circulation 197

CHAPTER **8**
The Waves 229

CHAPTER **9**
The Tides 259

CHAPTER **10**
Coasts, Beaches, and Estuaries 279

CHAPTER **11**
The Living Ocean 309

CHAPTER **12**
The Plankton, Productivity,
and Food Webs 331

CHAPTER **13**
The Nekton: Swimmers of the Sea 367

CHAPTER **14**
The Benthos: Living on the Sea Floor 397

CHAPTER **15**
Environmental Issues 427

CHAPTER **16**
The Oceans and Climate Disruption 455

Appendix A Scientific (or Exponential)
Notation 477

Appendix B SI Units 479

Appendix C Equations and Quantitative
Relationships 483

Glossary 487

Index 497

Contents

PREFACE XI

PROLOGUE

The History of Oceanography 3

- P.1** The Early Times 4
- P.2** The Middle Ages 7
- P.3** Voyages of Discovery 8
- P.4** The Importance of Charts and Navigational Information 10
- P.5** Ocean Science Begins 12
- P.6** Early Expeditions of the Nineteenth and Twentieth Centuries 14
 - The *Challenger* Expedition 14
 - The Voyage of the *Fram* 15
 - The *Meteor* Expedition 15
- P.7** Ocean Science in Modern Times 15
 - Establishing Oceanographic Institutions 15
 - Large-Scale, Direct Exploration of the Oceans 16

Diving in “FLIP,” the Floating Instrument Platform 17

Diving in Planning and Executing a Successful Oceanographic Expedition 21

- P.8** Oceanography from Space 23
 - The View from Space 23
 - Oceanographic Applications for Geology 25
 - Oceanographic Applications for Physics 27
 - Oceanographic Applications for Chemistry and Biology 28
 - Our Wired World 29
 - A Glimpse of Our Future 30

Summary 32

CHAPTER 1

The Water Planet 35

- 1.1** Cosmic Beginnings 36
 - Origin of the Universe 36
 - Origin of Our Solar System 37
 - Extraterrestrial Oceans 38

Diving in *Origin of the Oceans* 40

- Early Planet Earth 41
- 1.2** Earth’s Age and Time 41
 - Earth’s Age 41
 - Geologic Time 42
 - Natural Time Periods 44
- 1.3** Earth’s Shape 45



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Keith A. Sverdrup

- 1.4** Where on Earth Are You? 46
 - Latitude and Longitude 46
 - Measuring Latitude 48
 - Longitude and Time 48
- 1.5** Modern Navigation 49
- 1.6** Earth Is a Water Planet 50
 - Water on Earth’s Surface 50
 - Hydrologic Cycle 50
 - Reservoirs and Residence Time 51
 - Distribution of Land and Water 52
 - One World Ocean Divided into Five 52
 - Hypsographic Curve 55

Summary 56

Key Terms 56

Study Problems 57

CHAPTER 2

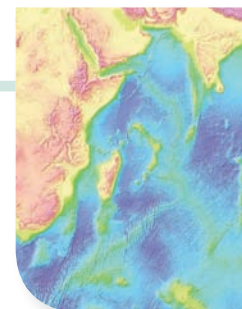
Earth Structure and Plate Tectonics 59

- 2.1** Earth’s Interior 60
 - Earthquake Waves Reveal Earth’s Layers 60
 - Model 1: Layers with Different Mineral and Chemical Compositions 61
 - Model 2: Layers with Different Strengths and Physical Properties 63
 - Isostasy 64
- 2.2** History of a Theory: Continental Drift 65
- 2.3** Evidence for a New Theory: Seafloor Spreading 67
 - Evidence for Crustal Motion 68
- 2.4** Plate Tectonics 74
 - Plates and Their Boundaries 75
 - Divergent Boundaries 75
 - Transform Boundaries 77
 - Convergent Boundaries 78
 - Continental Margins 81
- 2.5** Motion of the Plates 81
 - Mechanisms of Motion 81
 - Rates of Motion 82
 - Hotspots 84
- 2.6** History of the Continents 85
 - The Breakup of Pangaea 85
 - Before Pangaea 86

Summary 87

Key Terms 88

Study Problems 88



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CHAPTER 3

The Sea Floor
and Its Sediments 91

- 3.1 Measuring the Depths 92
- 3.2 Seafloor Provinces 95
 - Continental Margins and Submarine Canyons 96
 - Abyssal Plains 97
 - Ridges, Rises, and Trenches 98

Diving in *Exploring the Mariana Trench* 100

- 3.3 Sediments 102
 - Why Study Sediments? 102
 - Classification Methods 102
 - Particle Size 102
 - Location and Rates of Deposition 103
 - Source and Chemistry 104
 - Patterns of Deposit on the Sea Floor 108
 - Formation of Rock 111
 - Sampling Methods 111
 - Sediments as Historical Records 112
- 3.4 Seabed Resources 114
 - Sand and Gravel 114
 - Phosphorite 115
 - Oil and Gas 115
 - Gas Hydrates 115
 - Manganese Nodules 116
 - Sulfide Mineral Deposits 117

Summary 117

Key Terms 118

Study Problems 119

CHAPTER 4

The Physical Properties
of Water 121

- 4.1 The Water Molecule 122
- 4.2 Temperature and Heat 122
- 4.3 Changes of State 125
- 4.4 Specific Heat 126
- 4.5 Cohesion, Surface Tension, and Viscosity 127
- 4.6 Density 127
 - The Effect of Pressure 128
 - The Effect of Temperature 128
 - The Effect of Salt 129
- 4.7 Transmission of Energy 130
 - Heat 130
 - Light 131
 - Sound 134

Diving in *The Acoustic World of Marine Organisms and the Problem of Anthropogenic Noise* 137

Summary 139

Key Terms 139

Study Problems 139



Keith A. Sverdrup



Keith A. Sverdrup

CHAPTER 5

The Chemistry
of Seawater 141

- 5.1 Salts 142
 - Dissolving Ability of Water 142
 - Units of Concentration 142
 - Ocean Salinities 143
 - Dissolved Salts 144
 - Sources of Salt 144
 - Regulating the Salt Balance 145
 - Residence Time 147
 - Constant Proportions 148
 - Determining Salinity 148
- 5.2 Gases 149
 - Distribution with Depth 149
 - The Carbon Dioxide Cycle 150
 - The Oxygen Balance 150
 - Measuring the Gases 150
- 5.3 Carbon Dioxide and the Ocean 151
 - The pH of Seawater 151
 - The Marine Carbonate System and Buffering pH 152
 - Anthropogenic Carbon Dioxide and Ocean Acidification 153
- 5.4 Nutrients and Organics 154
 - Nutrients 154
 - Organics 155
- 5.5 Practical Considerations: Salt and Water 155
 - Chemical Resources 155
 - Desalination 155

Summary 157

Key Terms 158

Study Problems 158

CHAPTER 6

The Atmosphere
and the Oceans 161

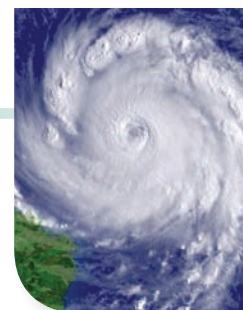
- 6.1 Heating and Cooling
 - Earth's Surface 162
 - Distribution of Solar Radiation 162
 - Heat Budget 163
 - Annual Cycles of Solar Radiation 164
 - Specific Heat and Heat Capacity 166
- Diving in** *Oceanography of Tidewater Glacier Margins: Undergraduate Research on Svalbard* 168
- 6.2 Sea Ice and Icebergs 170
 - Sea Ice 170
 - Icebergs 170
 - 6.3 Structure and Composition of the Atmosphere 171
 - Structure of the Atmosphere 171
 - Composition of Air 172
 - Carbon Dioxide and the Greenhouse Effect 172
 - Ozone 173

Diving in *Clouds and Climate* 174

- 6.4 The Atmosphere in Motion 176
 - Atmospheric Pressure 176
 - Winds on a Nonrotating Earth 176



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The Effects of Rotation 177
Wind Bands 179

- 6.5** Modifying the Wind Bands 181
Seasonal Changes 181
The Monsoon Effect 181
The Topographic Effect 183
- 6.6** Hurricanes and Coastal Flooding 185
Hurricanes 185
Coastal Flooding 185
- 6.7** El Niño–Southern Oscillation 191

Summary 194

Key Terms 195

Study Problems 195

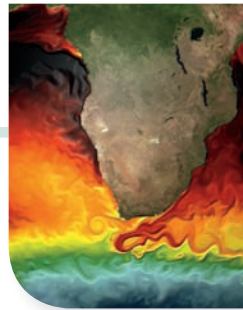
CHAPTER 7

Ocean Structure and Circulation 197

- 7.1** Ocean Structure 198
Variation of Temperature with Depth 198
Variation of Salinity with Depth 199
Variation of Density with Depth 200
- 7.2** Thermohaline Circulation and Water Masses 202
Thermohaline Circulation 202
Water Masses 203
- 7.3** The Layered Oceans 205
The Atlantic Ocean 205
The Pacific Ocean 206
The Indian Ocean 206
The Arctic Ocean 206
Internal Mixing 207
- 7.4** What Drives the Surface Currents? 207
The Ekman Spiral and Ekman Transport 208
Ocean Gyres 208
Geostrophic Flow 208
- 7.5** Ocean Surface Currents 209
Pacific Ocean Currents 209
Atlantic Ocean Currents 210
Indian Ocean Currents 210
Arctic Ocean Currents 210
Antarctic Currents 212
The Indonesian Throughflow 212
- 7.6** Current Characteristics 213
Current Speed 213
Current Volume Transport 213
Western Intensification 213
- 7.7** Eddies 215
- 7.8** Convergence and Divergence 216
Langmuir Cells 216
Permanent Zones 217
Seasonal Zones 218
- 7.9** Global Meridional Overturning Circulation 220
- 7.10** Changing Circulation Patterns 221
North Pacific Oscillations 221
North Atlantic Oscillations 221
- 7.11** Measuring the Currents 222

Diving in Ocean Drifters 223

Summary 226



Geophysical Fluid Dynamics
Laboratory

Key Terms 227

Study Problems 227

CHAPTER 8

The Waves 229

- 8.1** How a Wave Begins 230
Forces Influencing Waves 230
Two Types of Wind-Generated Waves 231
- 8.2** Anatomy of a Wave 232
- 8.3** Wave Speed 232
- 8.4** Deep-Water Waves in Detail 233
Deep-Water Wave Motion 233
Deep-Water Wave Speed 234
Storm Centers 234
Dispersion 234
Group Speed 235
Wave Interaction 235
Wave Height 236
Rogue Waves 238
Wave Energy 238
Wave Steepness 239
Universal Sea State Code 239
- 8.5** Shallow-Water Waves in Detail 239
Shallow-Water Wave Motion 239
Shallow-Water Wave Speed 240
Refraction 241
Reflection 242
Diffraction 242
- 8.6** The Surf Zone 243
Breakers 243
Water Transport and Rip Currents 244
Energy Release 245
- 8.7** Tsunami 246
- Diving in** The March 11, 2011, Japanese Tsunami 248
- 8.8** Internal Waves 251
- 8.9** Standing Waves 252
- 8.10** Practical Considerations: Energy from Waves 255

Summary 257

Key Terms 257

Study Problems 257

CHAPTER 9

The Tides 259

- 9.1** Tide Patterns 260
- 9.2** Tide Levels 260
- 9.3** Tidal Currents 261
- 9.4** Modeling the Tides 262
The Earth-Moon System 262
Earth and Moon Rotation 263
The Sun Tide 264
Spring Tides and Neap Tides 264
Declinational Tides 265
Elliptical Orbits 267
- 9.5** Real Tides in Real Ocean Basins 267
The Tide Wave 267



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Progressive Wave Tides 268
 Standing Wave Tides 268
 Tide Waves in Narrow Basins 270

9.6 Tidal Bores 270

9.7 Predicting Tides and Tidal Currents 271

Diving in *Measuring Tides from Space* 272

Tide Tables 273
 Tidal Current Tables 273

9.8 Practical Considerations: Energy from Tides 274

Summary 276

Key Terms 277

Study Problems 277

CHAPTER 10

Coasts, Beaches, and Estuaries 279

10.1 Major Coastal Zones 280

10.2 Types of Coasts 280
 Primary Coasts 283
 Secondary Coasts 284

10.3 Anatomy of a Beach 286

10.4 Beach Dynamics 288
 Natural Processes 288
 Coastal Circulation 290

10.5 Beach Types 291

10.6 Modifying Beaches 292
 Coastal Structures 292
 The Santa Barbara Story 293
 The History of Ediz Hook 294

10.7 Estuaries 295
 Types of Estuaries 296
 Circulation Patterns 297
 Temperate-Zone Estuaries 298

10.8 Regions of High Evaporation 298

10.9 Flushing Time 299

Summary 300

Diving in *Public Aquariums in Ocean Research and Education* 301

Key Terms 307

Study Problems 307

CHAPTER 11

The Living Ocean 309

11.1 Evolution in the Marine Environment 310

11.2 Marine Biodiversity 311

Diving in *Assessing Marine Biodiversity with Environmental DNA* 312

11.3 The Flow of Energy 314

11.4 Groups of Organisms 315

11.5 Environmental Zones 316



Dr. Matthew Fouse



Reinhard Dirscherl/agefotostock

Pelagic 316

Benthic 316

11.6 Facts of Life in the Ocean 317

Light 317
 Temperature 319
 Salinity 319

Diving in *Bioluminescence in the Sea* 320

Pressure 322
 Buoyancy 323
 Inorganic Nutrients 323
 Dissolved Gases 324
 pH 324

11.7 The Importance of Size 325

Summary 327

Key Terms 327

Study Problems 328

CHAPTER 12

The Plankton, Productivity, and Food Webs 331

12.1 The Marine Photoautotrophs 332

12.2 The Plankton 333

12.3 Bacterioplankton and Viruses 334

12.4 Phytoplankton 335
 Diatoms 336
 Dinoflagellates 337
 Coccolithophorids 338
 Cyanobacteria 339
 Prasinophytes 340
 Harmful Algal Blooms 340

12.5 Zooplankton 342

Diving in *Harmful Algal Bloom and Hypoxia Research and Control Act* 343

12.6 Primary Production 350

12.7 Measuring Primary Productivity 352

12.8 Phytoplankton Biomass 353

12.9 Controls on Productivity and Biomass 355

12.10 Food Webs and the Biological Pump 357
 Food Webs 357
 Biological Pump 359
 Marine Bacteria and Nutrients 359

12.11 Global Patterns of Productivity 360

Summary 363

Key Terms 364

Study Problems 364

CHAPTER 13

The Nekton: Swimmers of the Sea 367

13.1 The Nekton Defined 368



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- 13.2** Swimming Marine Invertebrates 369
- 13.3** Marine Reptiles 370
 - Sea Snakes 370
 - Sea Turtles 370
- 13.4** Marine Birds 372
- 13.5** Fish 374
 - Jawless Fish 374
 - Sharks, Skates, and Rays 374
 - Bony Fish 377
 - Deep-Sea Species of Bony Fish 378
- 13.6** Marine Mammals 380
 - Sea Otters 381
 - Walrus 381
 - Polar Bears 382
 - Seals and Sea Lions 384
 - Sea Cows 384
 - Whales 385
 - Whaling 387
 - Marine Mammal Protection Act 390
 - Communication 391

Diving in *Whale Falls* 392

Summary 394

Key Terms 394

Study Problems 395

CHAPTER 14

The Benthos: Living on the Sea Floor 397

- 14.1** The Benthic Environment 398
- 14.2** Seaweeds and Marine Plants 401
 - General Characteristics of Benthic Algae 401
 - Kinds of Seaweeds 403
 - Marine Plant Communities 404
- 14.3** Organisms of the Rocky Shore 404
 - Tide Pools 409
 - Submerged Rocky Bottoms 409
- 14.4** Organisms of the Soft Substrates 410
- 14.5** Organisms of the Deep-Sea Floor 413
- 14.6** Coral Reefs 415
 - Tropical Corals 415
 - Tropical Coral Reefs 416
 - Coral Bleaching 418
 - Predation and Disease 418
 - Human Activities 418

Diving in *Undersea Ultraviolet Radiation* 419

Deep-Water Corals 420

- 14.7** Deep-Ocean Chemosynthetic Communities 421
 - Hot Vents 421
 - Cold Seeps 422
- 14.8** Symbiosis 422

Summary 424

Key Terms 424

Study Problems 425



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CHAPTER 15

Environmental Issues 427

- 15.1** Human Impacts Through Time 428
- 15.2** Marine Pollution 428
 - Solid Waste Dumping 429
 - Sewage Effluent 430
 - Toxicants 430
- 15.3** Plastic Trash 433
- 15.4** Eutrophication and Hypoxia 436
- 15.5** Oil Spills 438

Diving in *Impacts from the Deepwater Horizon Spill* 440

- 15.6** Marine Wetlands 443
- 15.7** Biological Invaders 444
- 15.8** Overfishing and Incidental Catch 446
 - Trends in Fishing Pressure 446
 - Indirect Impacts 447
 - Fish Farming 448
 - Ecosystem-Based Fishery Management 449
- 15.9** Aftershoughts 450

Summary 451

Key Terms 452

Study Problems 452

CHAPTER 16

The Oceans and Climate Disruption 455

- 16.1** Earth as a Whole: The Oceans and Climate 456
- 16.2** The Ocean and Climate Change 457
 - Earth's Past Climate 458
 - Earth's Present Climate 459
 - Earth's Future Climate 461
- 16.3** The Oceans in a Warmer World 463
 - Ocean Acidification 463
 - Rising Sea Level 464
 - Winds, Waves, and Storms 465

Diving in *Arctic Sea Ice Loss, Midlatitude Extreme Weather, and Superstorm Sandy* 466

Thermohaline Circulation 468
Biological Responses 468

- 16.4** Mitigation Strategies 469
 - Ocean Energy 469
 - Carbon Sequestration 470

Diving in *The Intergovernmental Panel on Climate Change* 472

The International Response 474

Summary 475

Key Terms 475

Study Problems 476

Appendix A Scientific (or Exponential) Notation 477

Appendix B SI Units 479

Appendix C Equations and Quantitative Relationships 483

Glossary 487

Index 497



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Preface

What's New in This Edition?

New pedagogical features include revised/new figures and photographs that provide improved graphic illustration of ideas and issues. Data and concepts are updated throughout the text, including the addition of critical terms to the glossary and a review of the appendices. This edition is closely tied to online resources in Connect, which support studying and learning for students as well as teaching and grading for instructors. Resources on Connect include figures, animations, movie clips, data analysis exercises, online quizzes, and course management software.

Specific Changes to Chapters

- **Prologue** A new *Diving In* box on Planning and Executing a Successful Oceanographic Expedition was added. Oceanography from Space was updated to include the latest generation of satellites, with a new section on the future of satellite oceanography.
- **Chapter 1** The discussion of the origin and early development of the universe has been updated. The latest Mars mission to seek signs of past microbial life on the planet and assess Mars' habitability is discussed. The discussion of modern navigation has been updated.
- **Chapter 2** The description of Loihi Seamount has been updated along with the evidence supporting plate tectonics as early as 3.6 billion years ago. The current locations of the magnetic poles has been updated.
- **Chapter 3** The discussion of seabed resources was updated.
- **Chapter 4** New "Quick Review" questions have been added.
- **Chapter 5** The discussion of the Keeling curve and ocean acidification has been updated.
- **Chapter 6** New figures have been added for several topics.
- **Chapter 7** The discussions of eddies and the Global Meridional Overturning Circulation have been updated. Information on the Antarctic circumpolar current has been updated, a discussion of the Pacific decadal oscillation has been expanded, and a discussion of the Atlantic multi-decadal oscillation has been added.
- **Chapter 8** The concept of dynamic fetch has been updated. New "Quick Review" questions have been added.
- **Chapter 9** Figures have been updated and clarified. New "Quick Review" questions have been added.
- **Chapter 10** There are several new images of primary and secondary coasts as well as beach types.
- Public Aquariums in Ocean Research and Education.
- **Chapter 11** Content was updated.
- **Chapter 12** several figures were updated or replaced. New information on sea foam and harmful algae was added.
- **Chapter 13** New figures were added or replaced, and the content was updated.
- **Chapter 14** More emphasis on organism adaptations to the environment was included. More details about symbiosis were included.
- **Chapter 15** Content was updated.
- **Chapter 16** Content was updated.

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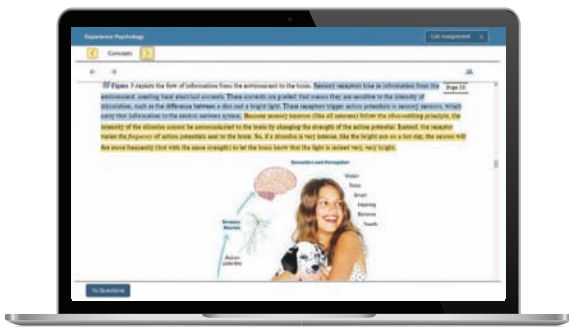
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PROLOGUE

The History of Oceanography

Learning Outcomes

After studying the information in this chapter students should be able to:


1. *discuss* the interaction of early civilizations with the oceans,
2. *sketch* the major seafaring routes of the great voyages of discovery in the fifteenth and sixteenth centuries, James Cook's voyages of discovery, and the scientific voyages of Charles Darwin and the *Challenger* expedition,
3. *list* the major discoveries of the *Challenger* expedition,
4. *compare* and *contrast* the methods of making scientific measurements in the nineteenth and twentieth centuries, and
5. *describe* the difference in both the quantity of oceanographic data and the density of that data available to oceanographers now compared to the nineteenth century.

Prologue Outline

- P.1 The Early Times 4
- P.2 The Middle Ages 7
- P.3 Voyages of Discovery 8
- P.4 The Importance of Charts and Navigational Information 10
- P.5 Ocean Science Begins 12
- P.6 Early Expeditions of the Nineteenth and Twentieth Centuries 14
 - Diving In: "FLIP," the Floating Instrument Platform 17*
 - Diving In: Planning and Executing a Successful Oceanographic Expedition 21*
- P.8 Oceanography from Space 23
- Summary 32

A sextant and marine charts. The sextant is an early navigational aid first constructed by John Bird in 1759.

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ceanography is a broad field in which many sciences are focused on the common goal of understanding the oceans. Geology, geography, geophysics, physics, chemistry, geochemistry, mathematics, meteorology, botany, and zoology have all played roles in expanding our knowledge of the oceans. Oceanography is often broken down into a number of subdisciplines.

Geological oceanography includes the study of Earth at the sea's edge and below its surface, and the history of the processes that form the ocean basins. Physical oceanography investigates the causes and characteristics of water movements such as waves, currents, and tides and how they affect the marine environment. It also includes studies of the transmission of energy such as sound, light, and heat in seawater. Marine meteorology (the study of heat transfer, water cycles, and air-sea interactions) is often included in the discipline of physical oceanography. Chemical oceanography studies the composition and history of the water, its processes, and its interactions. Biological oceanography concerns marine organisms and the relationship between these organisms and the environment in the oceans. Ocean engineering is the discipline that designs and plans equipment and installations for use at sea.

The study of the oceans was promoted by intellectual and social forces as well as by our needs for marine resources, trade and commerce, and national security. Oceanography started slowly and informally; it began to develop as a modern science in the mid-1800s and has grown dramatically, even explosively, in the last few decades. Our progress toward the goal of understanding the oceans has been uneven and progress has frequently changed direction. The interests and needs of nations as well as the scholarly curiosity of scientists have controlled the ways we study the oceans, the methods we use to study them, and the priority we give to certain areas of study. To gain perspective on the current state of knowledge about the oceans, we need to know something about the events and incentives that guided people's previous investigations of the oceans.

P.1 The Early Times

People have been gathering information about the oceans for millennia, accumulating bits and pieces of knowledge and passing them on by word of mouth. Curious individuals must have acquired their first ideas of the oceans from wandering the seashore, wading in the shallows, and gathering food from the ocean's edges. During the Paleolithic period, humans developed the barbed spear, or harpoon, and the gorge. The gorge was a double-pointed stick inserted into a bait and attached to a string.

At the beginning of the Neolithic period, the bone fishhook was developed and later the net. Metal fishhooks were first produced by the Egyptians. When this happened is still a question being studied, but most sources date this at 2500 to 2000 B.C.

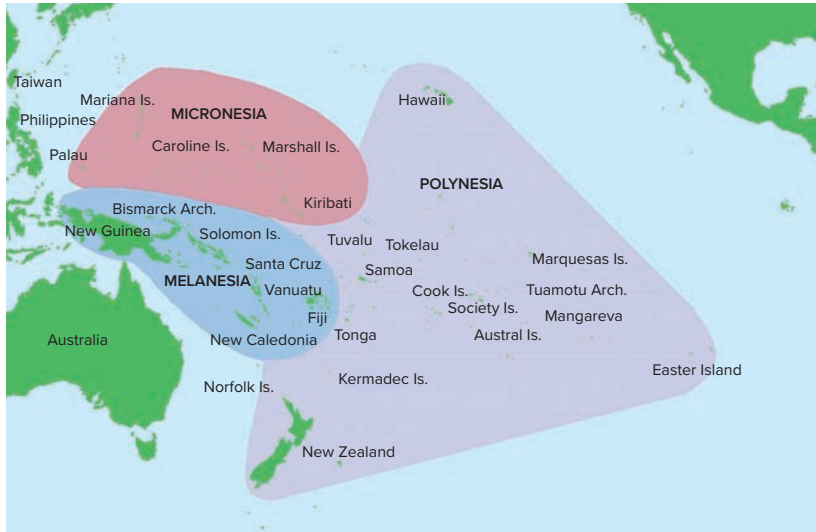
The remains of shells and other refuse, in piles known as kitchen middens, have been found at the sites of ancient shore settlements. These remains show that our early ancestors gathered shellfish, and fish bones found in some middens suggest that they also used rafts or some type of boat for offshore fishing. The artifacts that have been found probably give us only an idea of the minimum extent of ancient shore settlements. Drawings on the walls of the tomb of Ti (a high-ranking Egyptian official in the Fifth Dynasty, about 2400 B.C.) show fishermen using nets. As long ago as 1200 B.C. or earlier, dried fish were traded in the Persian Gulf; in the Mediterranean, the ancient Greeks caught, preserved, and traded fish, while the Phoenicians founded fishing settlements, such as "the fisher's town" Sidon, that grew into important trading ports.

Early information about the oceans was mainly collected by explorers and traders. These voyages left little in the way of recorded information. Using descriptions passed down from one voyager to another, early sailors piloted their way from one landmark to another, sailing close to shore and often bringing their boats up onto the beach each night.

Some historians believe that seagoing ships of all kinds are derived from early Egyptian vessels. The first recorded voyage by sea was led by Pharaoh Snefru about 3200 B.C. In 2750 B.C., Hannu led the earliest documented exploring expedition from Egypt to the southern edge of the Arabian Peninsula and the Red Sea.

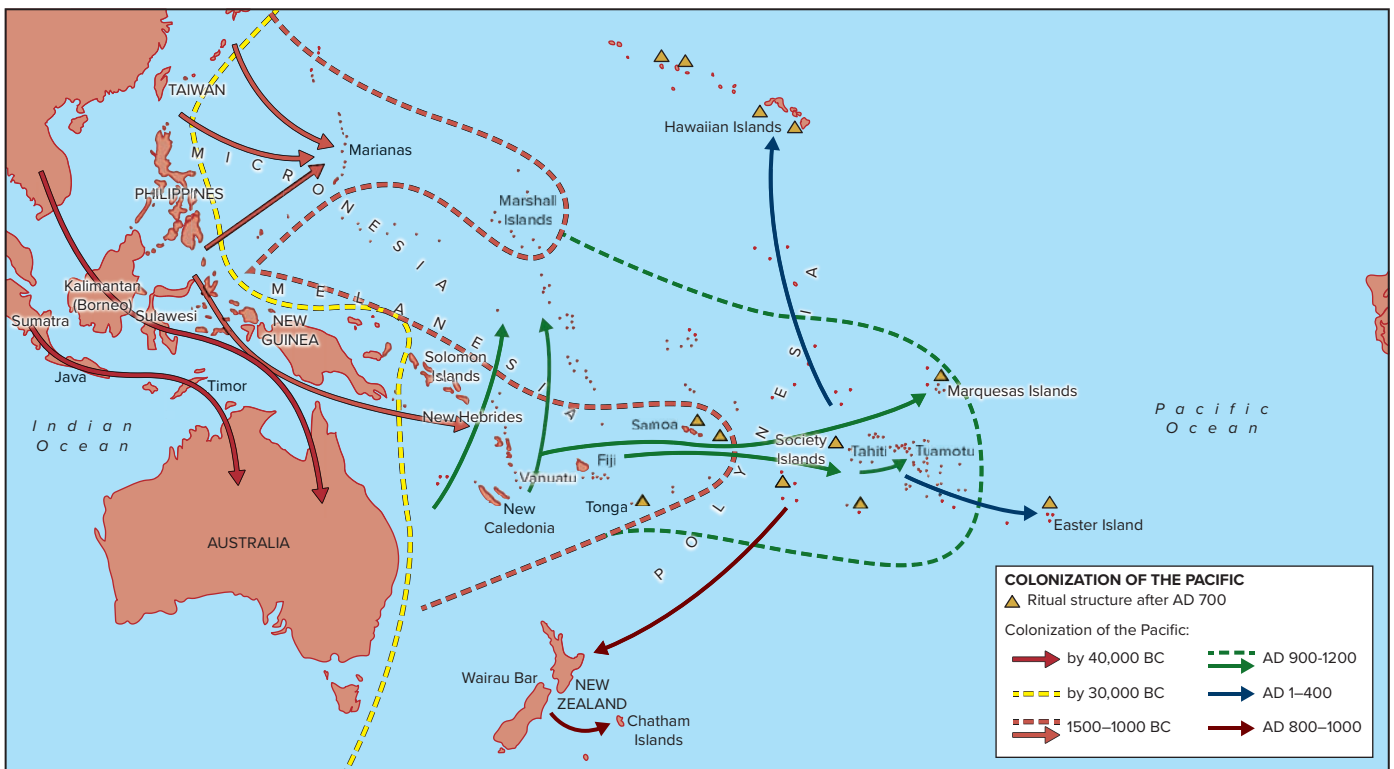
The Phoenicians, who lived in present-day Lebanon from about 1200 to 146 B.C., were well known as excellent sailors and navigators. While their land was fertile it was also densely populated, so they were compelled to engage in trade to acquire many of the goods they needed. They accomplished this by establishing land routes to the east and marine routes to the west. The Phoenicians were the only nation in the region at that time that had a navy. They traded throughout the Mediterranean Sea with the inhabitants of North Africa, Italy, Greece, France, and Spain. They also ventured out of the Mediterranean Sea to travel north along the coast of Europe to the British Isles and south to circumnavigate Africa in about 590 B.C.

Evidence from anthropology and archeology suggests that the people who first explored and populated the Pacific Ocean basin migrated from Asia first into the western Pacific regions now known as Micronesia and Melanesia, and later into the eastern Pacific region known as Polynesia (fig. P.1a). This historic migration is remarkable in terms of the size of the region and the sparse land within it. The Pacific Ocean extends over a third of Earth's surface and includes thousands of islands, most of which are quite small. As a general rule, as one travels eastward from Southeast Asia, the islands are smaller in size and the distances between them are greater and native island biota is less diverse. The timing of exploration and colonization of the Pacific Ocean remains a matter of scientific investigation. Present evidence suggests colonization of these regions took place in three phases (fig. P.1b). By at least 40,000 years ago, human groups travelled to Australia, Borneo, and New Guinea. In an initial phase, people



(a)

Figure P.1 (a) Exploration and colonization of the Pacific Ocean took place across three regions: Micronesia, Melanesia, and Polynesia. (b) Migration occurred in three phases, an initial phase throughout Micronesia and western Melanesia by about 1500–1000 B.C., a second phase as far east as Fiji, Tonga, and Samoa, occurred by A.D. 1500–1000 and a third phase, which occurred largely by A.D. 900–1200 into eastern Polynesia including the triangular region from the Hawaiian Islands in the north, to New Zealand in the south, and Rapa Nui (Easter Island) in the east. It is thought the Polynesians reached Rapa Nui by about A.D. 300 and the Hawaiian Islands by about A.D. 400.



(b)

known as the Austronesians migrated from Asia and settled the Marianas and Marshall Islands in Micronesia and New Guinea, and the Bismarck Archipelago and Solomon Islands in Melanesia by roughly 1500–1000 B.C. The second phase, which is known as the “Lapita colonization” for the Lapita ceramics that form an archeological trail as far east as Fiji, Tonga, and Samoa, occurred by A.D. 1500–1000. Lapita ceramics are named after the region in New Caledonia where the pottery was first identified. This led to the development of the distinctive Polynesian culture. The third phase of colonization, which occurred largely by A.D. 900–1200 is that of eastern Polynesia including the triangular region from the Hawaiian Islands in the north, to New Zealand in

the south, and Rapa Nui (Easter Island) in the east. It is thought the Polynesians reached Rapa Nui by about A.D. 300 and the Hawaiian Islands by about A.D. 400.

A basic component of navigation throughout the Pacific was the careful observation and recording of where prominent stars rise and set on the horizon. Observed near the equator, the stars appear to rotate from east to west on a north-south axis. Some rise and set farther to the north and some farther to the south, and they do so at different times. Navigators created a “star structure” by dividing the horizon into thirty-two segments where their known stars rose and set. These directions form a compass and provide a reference for recording information about the direction of winds,



Figure P.2 On Satawal Island, master navigator Mau Piailug teaches navigation to his son and grandson with the help of a star compass. The compass consists of an outer ring of stones, each representing a star or a constellation when it rises or sets on the horizon, and an inner ring of pieces of palm leaf representing the swells, which travel from set directions, and together with the stars, help the navigator find his way over the sea. In the center of the ring, the palm leaves serve as a model outrigger canoe.

Anders Ryman/Corbis Documentary/Getty Images

currents, waves, and the relative positions of islands, shoals, and reefs (fig. P.2). The Polynesians also navigated by making close observations of waves and cloud formations. Observations of birds and distinctive smells of land such as flowers and wood smoke alerted them to possible landfalls. Once islands were discovered, their locations relative to one another and to the regular patterns of sea swell and waves bent around islands could be recorded with stick charts constructed of bamboo and shells (fig. P.3).

As early as 1500 B.C., Middle Eastern peoples of many different ethnic groups and regions were exploring the Indian Ocean. In the seventh century A.D., they were unified under Islam and controlled the trade routes to India and China and consequently the commerce in silk, spices, and other valuable goods. (This monopoly wasn't broken until Vasco da Gama defeated the Arab fleet in 1502 A.D. in the Arabian Sea.)

The Greeks called the Mediterranean “Thalassa” and believed that it was encompassed by land, which in turn was surrounded by the endlessly circling river Oceanus. In 325 B.C., Alexander the Great reached the deserts of the Mekran Coast, now a part of Pakistan. He sent his fleet down the coast in an apparent effort to probe the mystery of Oceanus. He and his troops had expected to find a dark, fearsome sea of whirlpools and water spouts inhabited by monsters and demons; they did find tides that were unknown to them in the Mediterranean Sea. Pytheas (350–300 B.C.), a navigator, geographer, astronomer, and contemporary of Alexander, made one of the earliest recorded voyages from the Mediterranean to England. From there, he sailed north to Scotland, Norway, and Germany. He recognized a relationship between the tides and the Moon, and made early attempts at determining latitude and longitude. These early sailors did not investigate the oceans; for them, the oceans were only a dangerous road, a pathway from here to there, a situation that continued for hundreds of years. However, the



Figure P.3 A navigational chart (*rebillib*) of the Marshall Islands. Sticks represent a series of regular wave patterns (swells). Curved sticks show waves bent by the shorelines of individual islands. Islands are represented by shells.

Sea and Shore Museum, Port Gamble, WA

information they accumulated slowly built into a body of lore to which sailors and voyagers added each year.

While the Greeks traded and warred throughout the Mediterranean, they observed the sea and asked questions. Aristotle (384–322 B.C.) believed that the oceans occupied the deepest parts of Earth's surface; he knew that the Sun evaporated water from the sea surface, which condensed and returned as rain. He also began to catalog marine organisms. The brilliant Eratosthenes (c. 276–195 B.C.) of Alexandria, Egypt, invented the study of geography as well as a system of latitude and longitude. He was the first person to calculate the tilt of Earth's axis. One of his greatest achievements was his calculation of Earth's circumference; he accomplished this without ever leaving Egypt (fig. P.4). Eratosthenes knew that at local noon on the summer solstice, the Sun would be directly overhead in the city of Syene, located on the Tropic of Cancer at $23\frac{1}{2}^{\circ}\text{N}$. On that day and at that time, the Sun's rays would shine down into a well in the city and illuminate the bottom of the well. At the same time and day, the Sun's rays would cast a shadow behind a pole in his home city of Alexandria due north of Syene. By measuring the height of the pole and the length of the shadow, Eratosthenes could calculate the angle away from perpendicular of the Sun's elevation in Alexandria, which he determined to be about 7.2° , or roughly $1/50$ of a circle. Assuming that the distance between the Sun and Earth is so large that all of the Sun's rays of light are parallel to each other when they reach Earth, Eratosthenes could say that the angle between Syene and Alexandria was also about 7.2° , or roughly $1/50$ of a circle.

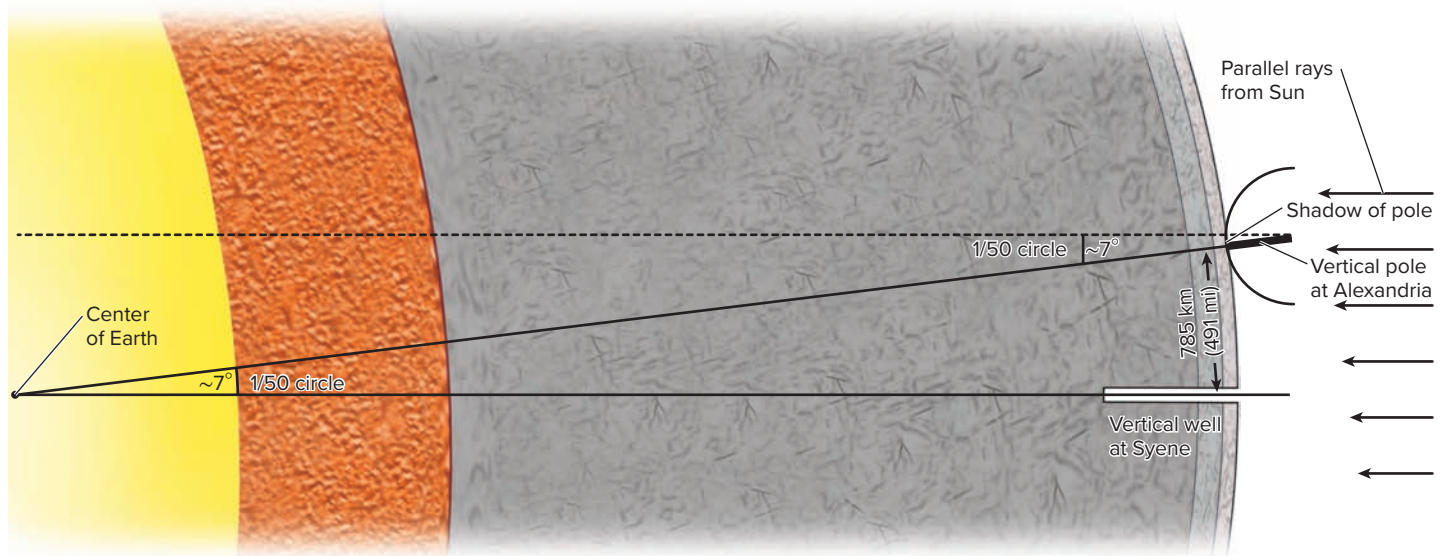


Figure P.4 Eratosthenes used geometry to calculate Earth's circumference. By careful measurement, he was able to estimate Earth's circumference to within about 1% of today's value. (The diagram is not drawn to scale.)

Repeated surveys of the distance between Syene and Alexandria yielded a distance of 5000 stadia, so Eratosthenes concluded that Earth's circumference was 252,000 stadia. The length of an Egyptian stadion was 157.5 m, so Eratosthenes's estimate of Earth's circumference was 39,690 km (24,662 mi), an error of only about 1% compared to today's accepted average value of about 40,030 km (24,873 mi). Posidonius (c. 135–50 B.C.) reportedly measured an ocean depth of about 1800 m (6000 ft) near the island of Sardinia, according to the Greek geographer Strabo (c. 63 B.C.–A.D. 21). Pliny the Elder (c. A.D. 23–79) related the phases of the Moon to the tides and reported on the currents moving through the Strait of Gibraltar. Claudius Ptolemy (c. A.D. ~85–161) produced the first world atlas and established world boundaries: to the north, the British Isles, Northern Europe, and the unknown lands of Asia; to the south, an unknown land, "Terra Australis Incognita," including Ethiopia, Libya, and the Indian Sea; to the east, China; and to the west, the great Western Ocean reaching around Earth to China. His atlas listed more than 8000 places by latitude and longitude, but his work contained a major flaw. He had accepted a value of 29,000 km (18,000 mi) for Earth's circumference. This value was much too small and led Columbus, more than 1000 years later, to believe that he had reached the eastern shore of Asia when he landed in the Americas.

QUICK REVIEW

1. Name the subfields of oceanography.
2. What did early sailors use for guidance during long ocean voyages?
3. What kind of "compass" did the Polynesians use for navigation?
4. How long ago was Earth's circumference first calculated, and how was it done?
5. How did Ptolemy's atlas contribute to a greater understanding of world geography, and how did it produce confusion?

P.2 The Middle Ages

After Ptolemy, intellectual activity and scientific thought declined in Europe for about 1000 years. However, shipbuilding improved during this period; vessels became more seaworthy and easier to sail, so sailors could make longer voyages. The Vikings (Norse for *piracy*) were highly accomplished seamen who engaged in extensive exploration, trade, and colonization for nearly three centuries from about 793 to 1066 (fig. P.5). During this time, they journeyed inland on rivers through Europe and western Asia, traveling as far as the Black and Caspian Seas. The Vikings are probably best known for their voyages across the North Atlantic Ocean. They sailed to Iceland in 871, where as many as 12,000 immigrants eventually settled. Erik Thorvaldsson (known as Erik the Red) sailed west from Iceland in 982 and discovered Greenland. He lived there for three years before returning to Iceland to recruit more settlers. Icelander Bjarni Herjolfsson, on his way to Greenland to join the colonists in 985–86, was blown off course, sailed south of Greenland, and is believed to have come within sight of Newfoundland before turning back and reaching Greenland. Leif Eriksson, son of Erik the Red, sailed west from Greenland in 1002 and reached North America roughly 500 years before Columbus.

To the south, in the region of the Mediterranean after the fall of the Roman Empire, Arab scholars preserved Greek and Roman knowledge and continued to build on it. The Arabic writer El-Mas'ûdî (d. 956) gives the first description of the reversal of the currents due to the seasonal monsoon winds. Using this knowledge of winds and currents, Arab sailors established regular trade routes across the Indian Ocean. In the 1100s, large Chinese junks with crews of 200 to 300 sailed the same routes (between China and the Persian Gulf) as the Arab dhows.

During the Middle Ages, knowledge of navigation increased. Harbor-finding charts, or *portolanos*, appeared. These charts carried a distance scale and noted hazards to navigation, but they did not have latitude or longitude. With the introduction of the magnetic compass to Europe from Asia in the thirteenth century, compass directions were added.

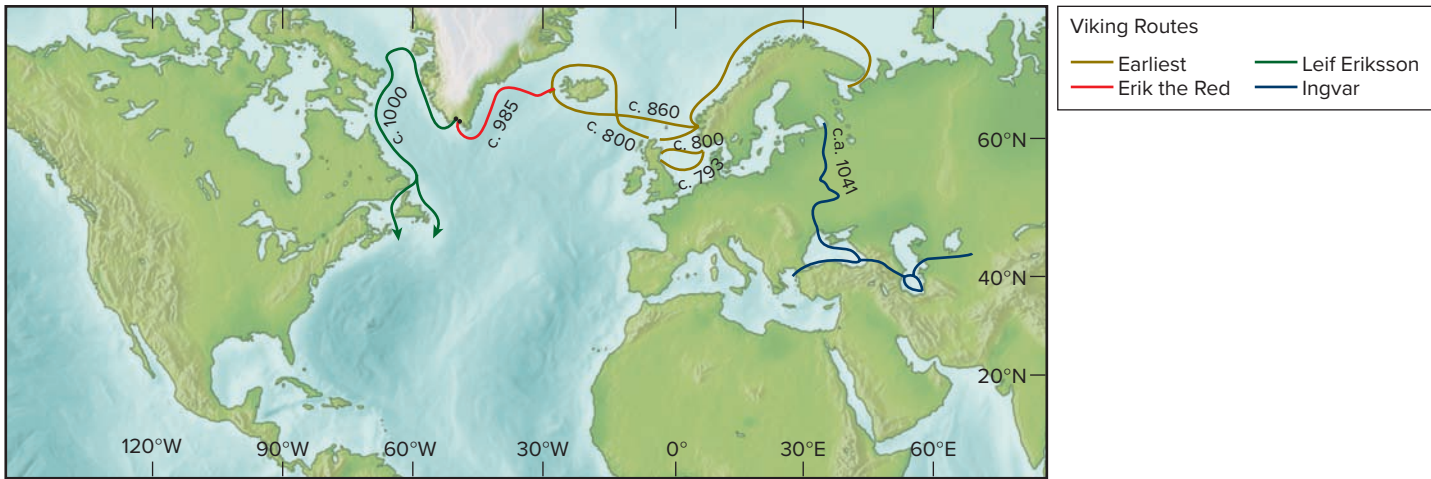


Figure P.5 Major routes of the Vikings to the British Isles, to Asia, and across the Atlantic to Iceland, Greenland, and North America.

Although tides were not understood, the Venerable Bede (673–735) illustrated his account of the tides with data from the British coast. His calculations were followed in the tidal observations collected by the British Abbot Wallingford of Saint Alban’s Monastery in about 1200. His tide table, titled “Flod at London Brigge,” documented the times of high water. Sailors made use of Bede’s calculations until the seventeenth century.

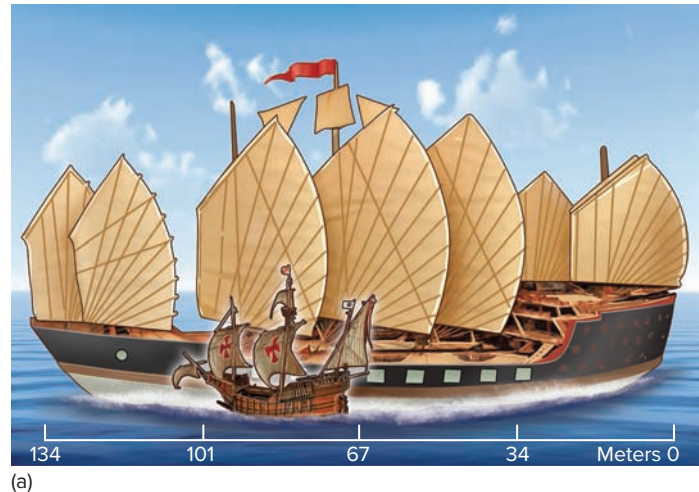
As scholarship was reestablished in Europe, Arabic translations of early Greek studies were translated into Latin and thus became available to European scholars. The study of tides continued to absorb the medieval scientists, who were also interested in the saltiness of the sea. By the 1300s, Europeans had established successful trade routes, including some partial ocean crossings. An appreciation of the importance of navigational techniques grew as trade routes were extended.

QUICK REVIEW

1. What advances occurred during the Middle Ages that allowed longer ocean voyages?
2. During the tenth century, which oceans were explored and by which cultures?
3. Where did the Vikings establish a large colony in the North Atlantic?

P.3 Voyages of Discovery

From 1405 to 1433, the great Chinese admiral Zheng He conducted seven epic voyages in the western Pacific Ocean and across the Indian Ocean as far as Africa. Zheng He’s fleet consisted of over 300 ships. The fleet is believed to have included as many as sixty-two “treasure ships” thought to have been as much as 130 m (426 ft) long and 52 m (170 ft) wide; this was ten times the size of the ships used for the European voyages of discovery during this period of time (fig. P.6). The purpose of these voyages remains a matter of debate among scholars. Suggested reasons include the establishment of trade routes, diplomacy with other governments, and military defense. The voyages ended in 1433, when



(b)

Figure P.6 (a) Admiral Zheng He’s “treasure ships” were over 130 m long. In comparison, Christopher Columbus’s flagship, the *Santa Maria*, is estimated to have been about 18 m long. (b) Zheng He’s probable route from China along the coast of the Indian Ocean to Africa.

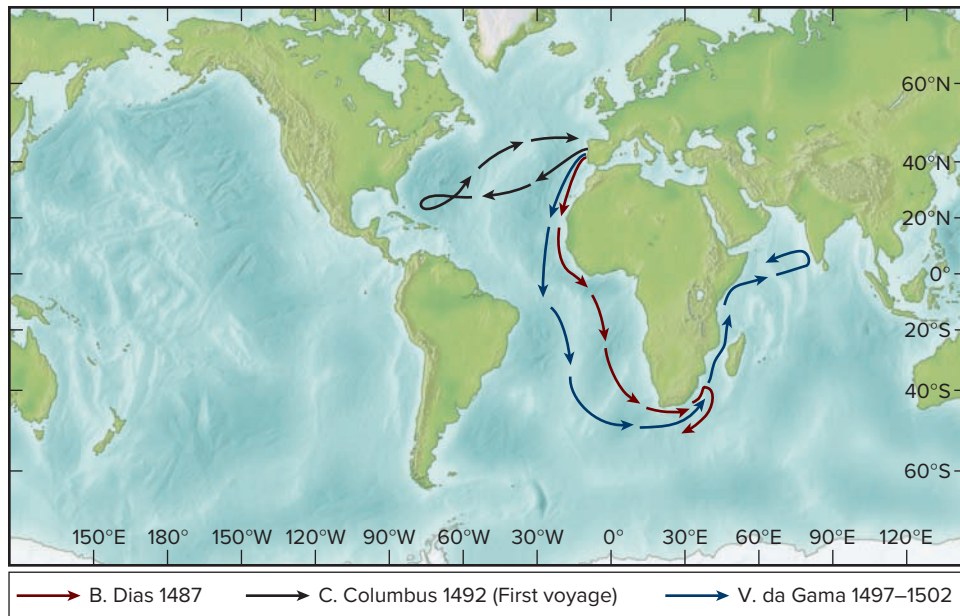


Figure P.7 The routes of Bartholomeu Dias and Vasco da Gama around the Cape of Good Hope and Christopher Columbus's first voyage.

their explorations led the Chinese to believe that other societies had little to offer, and the government of China withdrew within its borders, beginning 400 years of isolation.

In Europe, the desire for riches from new lands persuaded wealthy individuals, often representing their countries, to underwrite the costs of long voyages to all the oceans of the world. The individual most responsible for the great age of European discovery was Prince Henry the Navigator (1394–1460) of Portugal. In 1419, his father, King John, made him governor of Portugal's southernmost coasts. Prince Henry was keenly interested in sailing and commerce, and studied navigation and mapmaking. He established a naval observatory for the teaching of navigation, astronomy, and cartography about 1450. From 1419 until his death in 1460, Prince Henry sent expedition after expedition south along the west coast of Africa to secure trade routes and establish colonies. These expeditions moved slowly due to the mariners' belief that waters at the equator were at the boiling point and that sea monsters would engulf ships. It wasn't until twenty-seven years after Prince Henry's death that Bartholomeu Dias (1450–1500) braved these "dangers" and rounded the Cape of Good Hope in 1487 in the first of the great European voyages of discovery (fig. P.7). Dias had sailed in search of new and faster routes to the spices and silks of the East.

Portugal's slow progress along the west coast of Africa in search for a route to the east finally came to fruition with Vasco da Gama (1469–1524) (fig. P.7). In 1497, he followed Bartholomeu Dias's route to the Cape of Good Hope and then continued beyond along the eastern coast of the African continent. He successfully mapped a route to India but was challenged along the way by Arab ships. In 1502, da Gama returned with a flotilla of fourteen heavily armed ships and defeated the Arab fleet. By 1511, the Portuguese controlled the spice routes and had access to the Spice Islands. In 1513, Portuguese trade extended to China and Japan.

Christopher Columbus (1451–1506) made four voyages across the Atlantic Ocean in an effort to find a new route to the East Indies by traveling west rather than east. By relying on inaccurate estimates of Earth's size, he badly underestimated the distances involved and believed he had found islands off the coast of Asia when, in fact, he had reached the New World (fig. P.7).

Italian navigator Amerigo Vespucci (1454–1512) made several voyages to the New World (1499–1504) for Spain and Portugal, exploring nearly 10,000 km (6000 mi) of South American coastline. He accepted South America as a new continent not part of Asia, and in 1507, German cartographer Martin Waldseemüller applied the name "America" to the continent in Vespucci's honor. Vasco Núñez de Balboa (1475–1519) crossed the Isthmus of Panama and found the Pacific Ocean in 1513, and in the same year, Juan Ponce de León (1474?–1521)

discovered Florida and the Florida Current. All claimed the new lands they found for their home countries. Although these men had sailed for fame and riches, not knowledge, they more accurately documented the extent and properties of the oceans, and the news of their travels stimulated others to follow.

Ferdinand Magellan (1480–1521) left Spain in September 1519 with 270 men and five vessels in search of a westward passage to the Spice Islands. The expedition lost two ships before finally discovering and passing through the Strait of Magellan and rounding the tip of South America in November 1520. Magellan crossed the Pacific Ocean and arrived in the Philippines in March 1521, where he was killed in a battle with the natives on April 27, 1521. Two of his ships sailed on and reached the Spice Islands in November 1521, where they loaded valuable spices for a return home. In an attempt to guarantee that at least one ship made it back to Spain, the two ships parted ways. The *Victoria* continued sailing west and successfully crossed the Indian Ocean, rounded Africa's Cape of Good Hope, and arrived back in Spain on September 6, 1522, with eighteen of the original crew. This was the first circumnavigation of Earth (fig. P.8). Magellan's skill as a navigator makes his voyage probably the most outstanding single contribution to the early charting of the oceans. In addition, during the voyage, he established the length of a degree of latitude and measured the circumference of Earth. It is said that Magellan tried to test the mid-ocean depth of the Pacific with a hand line, but this idea seems to come from a nineteenth-century German oceanographer; writings from Magellan's time do not support this story.

The great Arabian navigator and cartographer Ahmad ibn Majid is known as "The Lion of the Sea." Ibn Majid wrote several books on marine science and navigation, perhaps the most important being *Book of Useful Information on the Principles and Rules of Navigation*, which he wrote in about 1490. It is a comprehensive