Chapter 1  Early Foundations of the Ocean Sciences  2

The Early Ocean Voyagers  3
The Principles of Navigation  5
The problem of scale  5
The problem of locating one’s position  7
Dealing with Spherical Geometry of the Earth  7
Latitude  7
Box 1A Degrees of Latitude in terms of Miles  9
Longitude  10
Box 1B Longitude and Time  12
Coming Out of the Dark Ages: The Renaissance Europeans  13
Box 1C The Magnetic Compass  14
Post-Renaissance Ocean Exploration  15
Box 1D The Search for the Northwest Passage  19
The Birth of Oceanography  20
The Challenger expedition  20
A note on technology and sampling problems of the times  22
Oceanography and Marine Biology: Late Nineteenth to Early Twentieth Century  25
Fridtjof Nansen  25
Growth of marine research  27

Chapter 2  Origins and Connections: Science, the Universe, Earth, and Life  32

What Is Science?  33
Science and technology  33
Ways of doing science  36
On “seeing” in science  37

Origins: Where Did the Earth and Its Oceans Come From?  38
The “Big Bang”  38
Box 2A Red Shift  40
Early formation of planet Earth  43
Origins of Earth’s water  45
Water elsewhere in the Universe  46
Earth’s Internal Structure  48
Chemical characteristics of Earth’s interior  48
Physical characteristics of Earth’s interior  49
An Introduction to Geophysics  50
Heat sources and heat flow  50
Concepts of mass, weight, density, and buoyancy  51
Seismic waves: Two types  52
Refraction of seismic waves  53
Passage of seismic waves through the Earth  54
The Origin of Life  56

Chapter 3  The Ocean Floor: Its Formation and Evolution  62

Box 3A Scientific Revolutions  63
Continental Drift  64
An emerging suspicion  64
Early evidence  64
A modern history of an old idea  66
Evidence begins to accumulate  71
Box 3B Seismographs and the Richter Magnitude Scale  73
Box 3C Satellite Altimetry  76
Paleomagnetism: The final proof?  80
Box 3D Paleomagnetism and Reversal of the Earth’s Magnetic Field  82
A unifying theory of plate tectonics  84
Filling in the details  88
Convection currents in the mantle: Further evidence  88
Tectonic plate boundaries  90
Other marine geological features  94
Contents

Marine Sediments 98
- Sediment sizes and dynamics 99
- Types and origins of sediments 100

Box 3E  The Hjulstrom Diagram 101
- Distribution of marine sediments 107

Box 3F  Methods of Studying Marine Sediments 108

Chapter 4  Water: Its Chemical and Physical Properties 112

Basic Chemistry: Chemical Bonds 113
- Box 4A  Atoms and Common Sense 115

Physical-Chemical Properties of Water 118
- Water’s high surface tension 118
- Water’s great dissolving power 118
- Water’s liquid form 119
- Water’s high heat capacity 120
- Water’s phases: Liquid, solid, and gas 123
- Water’s latent heat of melting and evaporation 124
- Water’s transparency to light 126

Salinity 126
- Distribution of salt in the sea 128
- Determining salinity 129

Box 4B  Different Salinities in Different Oceans 131

Density 132
- Temperature effects on density 132
- Salinity effects on density 134
- Ice 134

Properties of Salt Water 136
- Increasing salinity decreases heat capacity 136
- Increasing salinity increases density 136
- Increasing salinity lowers the temperature of maximum density 136
- Increasing salinity depresses the freezing point 137

Box 4C  Salt and the Surface Melting Effect 139
- Increasing pressure increases density 140
- Combined effects of temperature and salinity on density 140

Box 4D  A Word about Nomenclature 142

Vertical Structure in the Ocean 142
- The vertical structure of the ocean and the propagation of sound waves 143

Chapter 5  Atmospheric Circulation and Ocean Currents 150

Light in the Sea 151

Box 5A  Beer’s Law \( I = I_0 e^{-kz} \) 153

Box 5B  How to Measure Light Attenuation 155

Atmospheric Circulation 155
- Air 156
- Density of air and atmospheric pressure 156

Box 5C  Avogadro’s Number 157
- Solar heating of the Earth and atmosphere 160
- The Coriolis effect 163
- Global atmospheric circulation and the effect of Coriolis 167

Box 5D  Mathematical Derivation of the Coriolis Effect on a Baseball 168

Box 5E  The Jet Streams 171
- Smaller-scale patterns (weather) 171

Box 5F  Santa Ana Winds 174

Box 5G  From Tropical Disturbance to Hurricane 176

Ocean Circulation 178
- Ekman currents 179
- The major ocean gyres 180
- Western Boundary Currents 182
- Equatorial currents 183

Box 5H  The Gulf Stream 183
- Density-driven thermohaline circulation 185

Box 5I  Measuring Ocean Currents 188

Chapter 6  Waves and Tides 192

The Basics of Ocean Waves 193
- Capillary waves 194
- Surface gravity waves 195

Box 6A  The Speed of Ocean Waves 198
- Seas and swells 198
- Formation and evolution of wind waves 199
- Surf 203
- Wave interference 204
- Wave refraction and diffraction, and longshore currents 206
- Seiches 207
- Tsunami (or seismic sea waves) 208
- Internal waves 210
Tides 210
Understanding the forces at work 212
Box 6B The Tide-Generating Forces 216
Combined influences of the Sun and Moon 217
Tides in ocean basins 218
Tides in the Gulf of Maine and the Bay of Fundy 220
The importance of tides 222

Chapter 7 Introduction to Life in the Sea 226

The Basics of Marine Biology: Photosynthesis and Respiration 227
Box 7A Photosynthesis and Respiration: The Basics 230
Box 7B Important Biologically Mediated Chemical Reactions in the Oceans 231

Nutrients and Limiting Factors 232
Box 7C The Difference between Nutrients and Primary Production on Land and in the Ocean 233

Biological Production in the Oceans 233
The phosphorus cycle 234
The nitrogen cycle 235
Box 7D Nitrogen and Phosphorus Limitation in the Sea and in Freshwater 235
Upwelling 238
Box 7E Measuring Primary Production 241
Winter convective mixing and seasonal vertical stratification 241
The spring phytoplankton bloom 242
Box 7F Winter Cooling and Sinking 243
Box 7G The Spectacular Spring Bloom 245

Food Chains and Food Webs 246

Factors Controlling the Distribution of Marine Organisms 249
Distributions with depth 249
Box 7H Pressure Effects on Air Supply for a Scuba Diver 252
Distributions with latitude 253
Distributions with salinity: Distance from shore 254

Taxonomy of Marine Organisms 255
Box 7I Modern Taxonomic Structure 257

Chapter 8 The Primary Producers 260

The Phytoplankton 261
The Archaea 263
The Bacteria 263
The eukaryotic phytoplankton 267
Box 8A Plankton Nomenclature Based on Size 268
Ecological challenges faced by phytoplankton: Light and nutrients 277
Methods of studying phytoplankton 279
Harmful algal blooms and “red tides” 281

The Macroalgae (the Seaweeds) 286
The green algae 287
The red algae 288
The brown algae 289

Seagrasses 291

Chapter 9 The Zooplankton 296

The Meroplankton 297
The Holoplankton 301
The microzooplankton 301
Box 9A The Microbial Loop 303
The crustacean zooplankton 304
Box 9B Diatoms, Copepods, and Teratogenesis 311
Planktonic molluscs 313
The ctenophores 318
The chaetognaths 319
The appendicularians and salps 320
The ichthyoplankton 320

Chapter 10 Marine Invertebrates 324

The Benthos 327
The sponges 327
Sea anemones and corals 328
Bryozoa, phoronids, and brachiopods 331
The platyhelminthes, nemertians, and nematodes 332
Chapter 11  The Fishes  360

The Jawless Fishes  362
Hagfishes  363
Lampreys  363

The Cartilagenous Fishes  364
Chimaeras  365
Elasmobranchs: Sharks, skates, and rays  365

The Bony Fishes 370
Box 11A  The Coelacanth: A Fish Believed To Be Extinct Turned Out Not To Be, after All  370

General Biology of Marine Fishes 372
Respiration  372
Osmoregulation  374
Fish propulsion  374
Box 11B  A Word on “Top” Swimming Speeds in Fishes  375
Shoaling and schooling behavior  377
Fish feeding  378
Fish reproduction  380
Fish growth and mortality  381
Fish migrations  383

Box 11C  Determining the Age of a Fish Using Otoliths  385

The Field of Ichthyology  387

Chapter 12  Marine Environments  390

The Intertidal Zone 391
The rocky intertidal zone  394
The soft-bottom intertidal zone  398

Estuaries  401
Salt Marshes  405
Mangrove Forests  407

Chapter 13  Marine Reptiles, Birds, and Mammals  420

Marine Reptiles  421
Sea snakes  422
Marine iguanas  422
Saltwater crocodiles  423
Sea turtles  423

Sea Birds 425
General characteristics  425
Surface feeders  427
Pursuit feeders  427
Plunge divers  429
Scavengers, predators, and others  430
Shorebirds, raptors, and sea ducks  432

Marine Mammals  433
The sea otter  433
The sirenians  435
The pinnipeds  437
Fur seals and sea lions  437
Walruses  438
The true seals  439
Cetaceans: The whales, dolphins and porpoises  440
Cetacean feeding  441
Whale breathing  443
Deep diving  444
Swimming speed  445
Box 13A  “The Bends” and Deep-Diving Marine Mammals  446
Echolocation  446
Whale migrations  447
Cetacean intelligence  447

Whaling  449
Some case histories  451
Chapter 14
Marine Fisheries and Aquaculture 458

Fisheries Trophodynamics 460
A History of Commercial Fisheries 462
Types of fishing gear 464
Principles of Fishery Science 470
Growth and mortality 470
Maximum sustainable yield 473
Recruitment variability 474
Current Status and Management of Fisheries 477
Aquaculture 479

Chapter 15
Human Impacts 484

Marine Pollution 486
Nutrient enrichment and coastal eutrophication 486
Shipping, oil pollution, and nonindigenous species 491
Solid waste 494
Global Climate Change 496
The greenhouse effect 497
The evidence 499
Sea level 503

Appendix A: Satellite Remote Sensing A–1

Appendix B: El Niño and La Niña A–5

Appendix C: Exploring the Deep, Dark Ocean A–9

Glossary G–1
Illustration Credits IC–1
Index I–1