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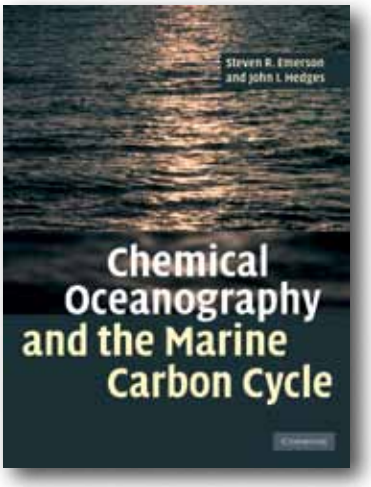
Chemical Oceanography and the Marine Carbon Cycle



By Steven Emerson and John Hedges, Cambridge University Press, 2008, 453 pages, 978-0-521-83313-4, Hardcover, $90 US

REVIEWED BY TIMOTHY SHAW

Chemical Oceanography and the Marine Carbon Cycle reflects the two authors' wealth of research and teaching experience, and the community is fortunate that Steve Emerson was able to complete this major effort following John Hedges' untimely death in 2003. This book is a compilation of many years' worth of notes used by the authors, professors of oceanography at the University of Washington, for teaching at both the undergraduate and graduate levels. The first seven chapters make up the core of their undergraduate chemical oceanography curriculum. The remaining five chapters reflect the additional material used in advanced graduate courses. It is partitioned so that an instructor can develop a course at any level by adding or omitting sections or chapters as necessary. This approach is essential in a field where students come to the subject from a wide range of scientific backgrounds. This book provides the chemistry background necessary to go beyond observations and conceptual models, providing the chemical theory that validates the models and explains observations. It is also refreshing to read a chemical oceanography book that presents organic chemistry and biochemistry of the ocean in appropriate detail. This book will make an excellent primary text for an upper level or graduate chemical oceanography course as well as an excellent reference for the advanced enthusiast.

Chapter 1 provides an appropriate introduction/review of a number of concepts critical to understanding the intersection between general oceanography and chemical oceanography. The chapter includes a brief discussion of the evolution of chemical oceanography, the units used in measuring critical physical and chemical properties of seawater, and the composition of seawater, and a review of the periodic table in terms of reactivity in the oceanographic context. This section offers a transition from a traditional view of chemical reactions at a molecular or elemental level to the empirical models that are necessarily used in chemical oceanography. The authors include a thorough discussion of concepts, such as thermohaline circulation and the biological control of chemical inventories, which are necessary for students with no general oceanographic background.

Chapter 2 presents mass balances and residence times as an approach to verifying large-scale reaction mechanisms in the ocean, starting from the pioneering work of Fred Mackenzie and Robert Garrels. The chapter clearly demonstrates how reactions can be scaled up to the ocean system and validated through estimates of input rates (reactants in) and removal rates (products out). The concepts of reaction rate measurements (as residence time) and identification of reaction products are intended to provide the tools necessary to develop mass balances in a complex system like the ocean. The discussion of the limitations of the Mackenzie and Garrels model leads into the discovery of hydrothermal vents and their importance to global chemical mass balances. This section includes the methods used to estimate the magnitude of hydrothermal flow and the associated chemical flux. The discussion demonstrates how estimates of ocean-scale reaction rates can be refined using a range of physical and chemical measurements.

Chapter 3 reviews chemical thermodynamics to introduce applications specific to chemical oceanography. The chapter presents important topics covered in most aquatic chemistry texts and expands on what is offered in typical freshman chemistry texts. These topics include free energy and equilibrium calculations, phase diagrams, and properties of gases in water. The prediction of reaction outcomes in complex systems like seawater relies on a strong working knowledge of thermodynamics. This chapter is an essential preface for the carbonate chemistry presented in Chapter 4 and later discussions.

Chapter 4 presents acid-base chemistry in the context of controls and

measurement of carbonic and boric acid speciation in seawater. The discussion covers the definition and measurement of alkalinity, models for calculating pH in seawater, and the kinetics of reactions in the carbonate system. The chapter ends with processes that control the carbonate system and alkalinity in seawater and includes detailed appendices supporting the calculations used in the chapter.

Chapter 5 is a necessary preface for later discussions of paleoceanography, ocean circulation, and stable isotope systematics in the context of the carbon cycle. The chapter includes stable isotope chemistry, analysis of isotope ratios, factors that lead to fractionation, and applications of stable isotope measurements. Similarly, the chapter presents radioactive isotopes in terms of sources, distributions, and applications to evaluation of rates pertinent to oceanographic applications.

Chapter 6 introduces biological processes in the ocean in the context of their responses to physiochemical processes and impacts on chemical inventories in the ocean. It also introduces the simple two-layer box models as a means of testing large-scale exchange between the surface and the deep ocean. The major biological processes, photosynthesis and respiration, are discussed in detail in the context of chemical composition and nutrient use and limitation. Organic carbon sequestration and export are presented in the context of methods of measuring rates of uptake and export from the surface ocean. This chapter also demonstrates applications for chemical "tools" presented in earlier chapters (e.g., stable isotopes, radiotracers, mass balance).

Chapter 7 describes the application of chemical tracers to the reconstruction of past ocean physical and chemical properties, past atmospheric chemistry, and reconstruction of past Earth temperature. This chapter sets the stage for later discussions of the carbon cycle in the ocean in the context of past shifts in global temperature and changes in atmospheric CO_2. It emphasizes techniques and applications of chemical tracers (as correlations of changes in ocean chemistry with geological and atmospheric records) in a climatological and geological framework. The discussion provides critical background for students will little or no earth science training.

Chapter 8 addresses an important subfield in chemical oceanography—marine organic geochemistry—and provides enough essential background for students with little or no training in organic chemistry. The chapter includes a simple refresher on the components that make up organic molecules, followed by a more detailed section describing the methods for characterizing organic compounds and fundamental units of bio-molecules. The chapter also provides a thorough background in the techniques used to characterize organic compounds, including isotopic and molecular tracers.

Chapter 9 covers reaction rates and diffusion in aquatic systems. It presents the physical basis for diffusion and the methods for calculating diffusion coefficients. The authors continue with a brief introduction to kinetics, leading to a derivation of the relationship between reaction rates (forward and back) and near-equilibrium conditions. This section includes discussion of reaction order, rate-limiting steps in reactions, and determination of reaction rates. Like Chapters 3 and 8, this chapter provides critical chemistry background that is essential for nonchemists and is an excellent overall review.

Chapter 10 covers gas/liquid exchange with a focus on models of exchange, methods of measurement in natural waters, specific physical mechanisms in the ocean, and consequences for CO_2 exchange in the ocean. This chapter compares models for gas exchange on the microscale, followed by a discussion of natural gaseous tracers of exchange (both stable gases and radionuclides) and results of model fits to natural systems. There is also a discussion of the importance of interrelated physical

UPCOMING REVIEWS

Ocean: Reflections on a Century of Exploration
by Wolf H. Berger, University of California Press, 519 pages

Estuaries: Dynamics, Mixing, Sedimentation, and Morphology
by David Prandle, Cambridge University Press, 236 pages

Living at the Micro Scale: The Unexpected Physics of Being Small
by David B. Dusenbery, Harvard University Press, 416 pages

and chemical processes in the ocean (e.g., bubble injection, surface films) and quantification of the associated gas flux. The chapter closes by covering specific chemical interactions that affect gas exchange.

Chapter 11 presents the global carbon cycle in the context of the increase of anthropogenic carbon in the atmosphere and ocean, and it explains mechanisms of atmosphere-ocean carbon exchange through chemical and biological processes (the "solubility pump" and the "biological pump"). The chapter also offers detailed discussions of the history, mechanisms, and outcomes of partitioning of anthropogenic carbon among the atmospheric, terrestrial, and oceanic reservoirs (e.g., the Revelle factor and the Keeling curve). This chapter provides important context for many of the chemical tools presented in the book through a contemporary application of major societal interest.

Chapter 12 ends the book with a presentation of reactions in sediments, including organic mater diagenesis, preservation of biogenic carbonate and silica, and the cycling of metals. The chapter presents the energetics of organic carbon degradation through the progression of available oxidants, and includes factors that control respiration and preservation of organic carbon. There is an excellent discussion of kinetics and thermodynamics in sedimentary environments in the presentation on carbonate and silica cycling. The chapter closes with metal cycling in sediments. The discussion includes thermodynamic models of metal dynamics (e.g., the redox cycling of Fe and Mn) as well as conceptual models based on empirical observations.

This book bridges the important gap between existing texts that assume a low level of chemistry background and those that stress chemical theory at the expense of oceanographic applications. The careful presentation of important oceanographic "problems" interspersed with the necessary review of pure chemistry, biology, and earth science makes this book appropriate for a very broad audience. It is a much-needed addition to the tools for teaching chemical oceanography at both the undergraduate and graduate levels.

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Strait Through The Ice

A film by Yves Billy, Icarus Films, 2007, 52 minutes, $390 US

REVIEWED BY JAMES P.M. SYVITSKI

Strait Through The Ice examines the geopolitical ramifications of the opening of the Northwest Passage due to global warming. The film offers viewers stunning vistas of this territory, as it follows the crew of the Canadian Coast Guard research icebreaker *Amundsen* through the Passage. A summertime, ice-free corridor would save the maritime industry some 4000 km on routes between Europe and Asia, primarily to Japan and China. Other economic activities in the Canadian Arctic would also expand, as freight ships would become available to offload their cargos.

The film concentrates on Canadian experts, who offer their opinions as to why and how Canada wants to control this potential shipping traffic through its Arctic Archipelago. The Canadian government has recently stepped up its presence in the area through more intensive surveying and icebreaker operations.

The narration is presented in English, and most of the interviews with scientists, shipping executives, local residents, navigational workers, and military leaders are also in English. A few interviews conducted with French-speaking sources are subtitled in English.

The film leaves much to be desired in terms of balance and information. Given how much of the discussion focuses on American opinions and claims that the Northwest Passage is an international navigable waterway, no Americans were interviewed, nor were representatives of other nations. This lack of balance is significant, particularly because, in 1957, American Coast Guard cutters were the first ships to sail the Northwest Passage using a deep draft route. Nowhere in the documentary was it mentioned that US submarines would commonly traffic the passage without any formal notification to the Canadian government. Nor