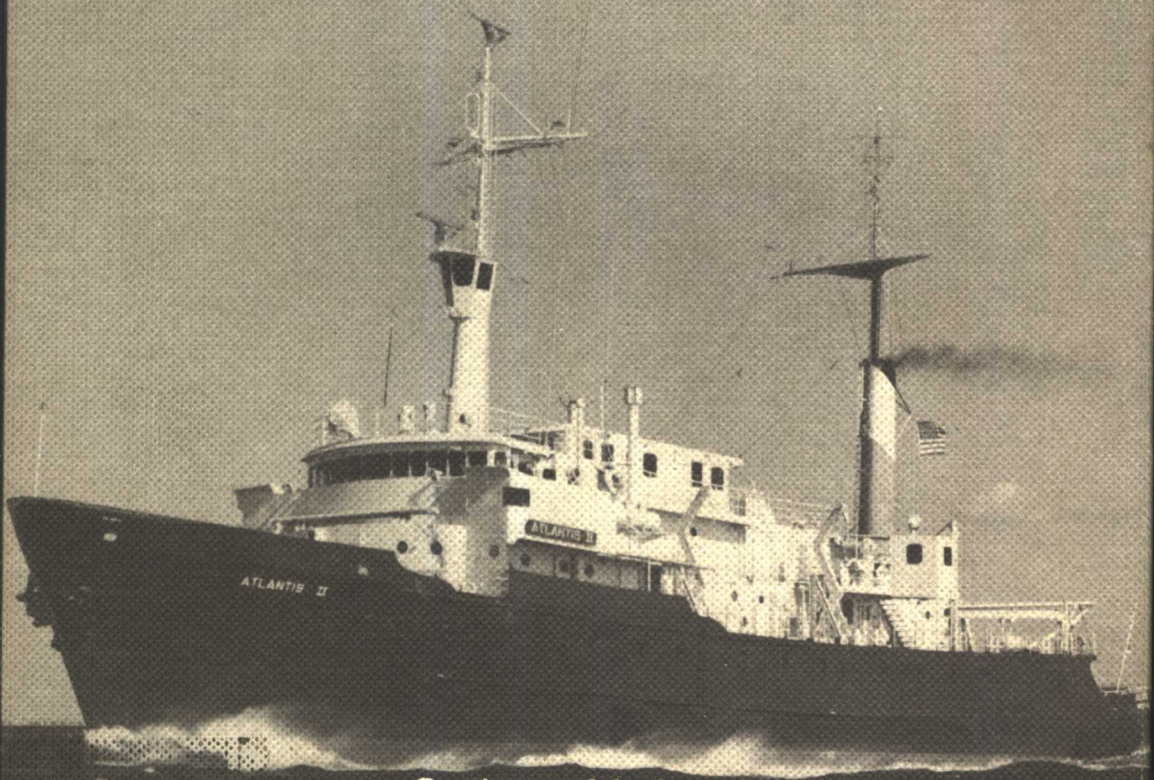
OCEANOGRAPHY

The Present and Future

Edited by
PETER G. BREWER



Springer-Verlag
New York Heidelberg Berlin

Oceanography
The Present and Future

Edited by
Peter G. Brewer

With 123 Figures

Springer-Verlag
New York Heidelberg Berlin

Peter G. Brewer
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543 USA

Library of Congress Cataloging in Publication Data
Main entry under title:
Oceanography, the present and future.
Subtitle: From the proceedings of Will we use the oceans wisely—the next fifty years in oceanography, a symposium on the future of oceanography, held September 29-October 2, 1980, at the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA, on the occasion of the fiftieth anniversary of the founding of the Institution.
Includes bibliographies and index.
1. Oceanography—Congresses. I. Brewer, Peter.
II. Woods Hole Oceanographic Institution.
GC2.028 1982 551.46 82-10480

Typeset by Ms Associates, Champaign, Illinois
Printed and bound by Halliday Lithograph, West Hanover, Massachusetts
Printed in the United States of America.

9 8 7 6 5 4 3 2 1

ISBN 0-387-90720-3 Springer-Verlag New York Heidelberg Berlin
ISBN 3-540-90720-3 Springer-Verlag Berlin Heidelberg New York

From the Proceedings of
Will We Use The Oceans Wisely—
The Next Fifty Years in Oceanography
A Symposium on the Future of Oceanography,
September 29—October 2, 1980, at the
Woods Hole Oceanographic Institution,
Woods Hole, Massachusetts, USA, on the
occasion of the Fiftieth Anniversary of
the founding of the Institution

Preface

Oceanography: The Present and Future is the proceedings of a symposium held at the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, on September 29-October 2, 1980 on the occasion of the fiftieth anniversary of the founding of the Institution. The symposium was immediately preceded by the Third International Congress on the History of Oceanography, also held at Woods Hole, and the proceedings of that Congress, *Oceanography: The Past*, also published by Springer-Verlag, forms a companion volume to this book.

The editorial responsibilities were handled by Ms. Kate Eldred, who worked extraordinarily hard on this volume, while the scientific editing was performed by Dr. Peter G. Brewer. The organizing committee of scientists charged with responsibility for the symposium was: Dr. Peter G. Brewer, chemistry; Dr. Arthur E. Maxwell, geology and geophysics; Dr. Robert W. Morse, marine policy; Dr. David A. Ross, marine policy and marine geology; Dr. Peter B. Rhines, physical oceanography; Dr. John A. Teal, marine biology; and Dr. Robert Spindel, ocean engineering. They were faced at the outset with the problem that science proceeds with intense effort and competition within a disciplinary peer group but that, particularly in ocean science, the results of this work often have completely unforseen and important consequences in a totally unrelated area.

Who could have foreseen, for instance, that the theory of plate tectonics and the quest for finding its thermal signature could have led to the discovery of radically new biological fauna living at high temperature and pressure in the ocean abyss? Yet this has indeed happened, and it is only a hint of oceanic processes yet to be discovered. Talks, therefore, were scheduled not along narrow disciplinary lines, but as groups by scale of oceanic processes: the small or molecular scale; the medium scale, covering events and distributions out to oceanic basin range; the global or planetary scale of climatic interest; and the human scale of engineering

and the human use of oceanic resources. Each day's session concluded with a talk and panel discussion on a marine policy issue to examine how the institutions of man utilize or affect the activities of ocean scientists. The papers in this volume appear in this format, much as they were presented.

Contributors to the symposium were invited to address the current status and future trends in their area of ocean science. It is, of course, impossible to cover the complexity of the oceans completely in one symposium. Nor is it possible to look very far into the future. What then is covered, and what do we see? J. Stewart Turner examines the smallest scales of ocean dynamics, where molecular differences in transport processes affect such diverse events as the mixing of Mediterranean water with the Atlantic Ocean and the debouching of 350°C brine on the floor of the Pacific. H.D. Livingston and W.J. Jenkins report on the fate of radioactive waste put into the oceans by man since the dawn of the atomic age, and attempt to chart its future course. Biologists G.R. Harbison and J.J. Childress, in separate papers, point out that our knowledge of the community of deep-sea biological species is being revolutionized by the simple ability now to carry out visual observations from submersibles or with scuba equipment. There are omissions too, and the editor feels keenly the loss of geological and geophysical contributions due to illness and unforeseen events affecting invitees. The volume is not a complete text, but a view of ocean science and policy as it stands today with a view of the future from key figures in the field.

The meetings were held in the Lillie Auditorium of the Marine Biological Laboratory, Woods Hole and were characterized by such entertaining presentations and stimulating discussions that a true anniversary spirit prevailed. Particular thanks go to Mr. Charles S. Innis, the hero of organization, and Mrs. Florence Mellor for attention to a thousand details. The scientific editor is particularly grateful to Ms. Kate Eldred, who bore the brunt of editing, of tracking down lost figures, and bringing order to diverse presentations. All members of the organizing committee reviewed papers in their area. Dr. Philip Manor and Ms. Ronnie Frankel of Springer Verlag were patient and professional in all their dealings with this group.

Support for the symposium was provided by the Office of Naval Research; the United States Geological Survey; the National Sea Grant Program; and the Woods Hole Oceanographic Institution.

Peter G. Brewer

Contributors and Their Affiliations

D. James Baker, Jr. University of Washington, School of Oceanography, University of Washington, Seattle, Washington 98195, USA

Alan Berman Director of Research, U.S. Naval Research Laboratory, Washington, D.C. 20390, USA

Bert Bolin University of Stockholm, Department of Meteorology, Arrhenius Laboratory, S-10691 Stockholm, Sweden

Frank G. Carey Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, USA

James J. Childress Department of Biology, University of California, Santa Barbara, California 93106, USA

Christopher Garrett Department of Oceanography, Dalhousie University, Halifax, Nova Scotia, Canada

Hillel Gordin Marine Acquaculture Research Station, Israel Oceanographic and Limnological Research, Ltd., Elat, Israel

G. Richard Harbison Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543 USA

Heinrich D. Holland Department of Geology, Harvard University, Cambridge, Massachusetts 02139, USA

William J. Jenkins Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, USA

Peter A. Larkin Institute of Animal Resource Ecology, University of British Columbia, Vancouver, B.C., Canada

Abrahim Lavi Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213, USA

Hugh D. Livingston Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, USA

Edward J. Miles School of Oceanography, University of Washington, Seattle, Washington 98195, USA

Walter J. Munk Scripps Institution of Oceanography, La Jolla, California 92039, USA

Evelyn Murphy Massachusetts Institute of Technology, Department of Urban Studies, Cambridge, Massachusetts 02139, USA

Pearn P. Niiler School of Oceanography, Oregon State University, Corvallis, Oregon 97331, USA

Orrin H. Pilkey Department of Geology and Marine Laboratory, Duke University, Durham, North Carolina 27706, USA

H. Thomas Rossby Graduate School of Oceanography, University of Rhode Island, Kingston, Rhode Island 02881, USA

John H. Steele Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, USA

J. Stewart Turner Australian National University, Research School of Earth Sciences, P.O. Box 4, Canberra 2600, Australia

John A. Whitehead, Jr. Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, USA

John M. Wood Gray Freshwater Biological Institute, P.O. Box 100, Navarre, Minnesota 55392, USA

Contents

Part I

Small- and Local-Scale Oceanography

Molecular Processes in the Marine Environment

John M. Wood

1 Introduction

In the past decade the possible fate of pollutants in the aquatic environment has received much attention. The pathways for heavy metals, chlorinated organic compounds, radioactive wastes, and atmospheric pollutants have been studied in both terrestrial and marine environments.[1] Ironically, much of this research, although analytically significant, has been performed without a full appreciation of the metabolic capabilities of organisms which live in aquatic systems. In order to understand the routes taken by man-made chemicals and pollutants we need some basic knowledge of the metabolic capabilities of aquatic biota. We need to answer some crucial questions of the marine environment such as: What are the biosynthetic pathways for halogenated natural products in the marine environment? How are halogenated natural products degraded? Do marine organisms have metabolic capabilities which are different from terrestrial organisms? What are the natural biological cycles for trace elements in the sea? What are the rate-limiting steps for metabolic processes in the sea? How important is a kinetic, rather than a thermodynamic, approach in studying marine ecosystems? Answers are crucial if we hope to understand the fates of pollutants in saltwater systems. I shall attempt to give a few hints on how some of these questions may be answered by adopting a classical biochemical approach. Although our knowledge is sketchy, there are sufficient examples to show that marine biota have evolved to deal with metabolism in a halide ion-rich environment.

2 Halogenation By Marine Biota

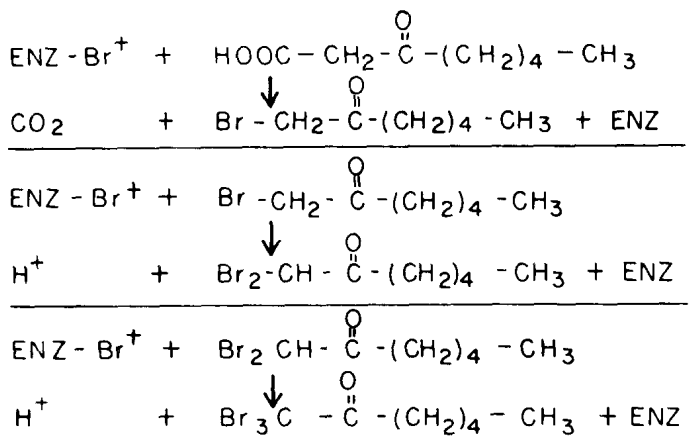
As early as 1940, Clutterbuck et al. showed that certain fungi were capable of using halide ions in the biosynthesis of halo-organic compounds as secondary metabolites. Later Shaw and Hager (1960) isolated an enzyme from the fungus

[1] For a general introduction see Fates of Pollutants, Commission on Natural Resources, National Academy of Sciences, Washington, D.C. (1977) and the Nature of Seawater, Physical & Chemical Sciences Research Report No. 1, Dahlem Konferenzen.

Caldariomyces fumago which catalyzed the oxidation of Cl^-, Br^-, and I^- to give an enzyme-bound electrophilic halogenating agent. This halogenating reagent was shown to react with a variety of nucleophiles to give halogenated reaction products. Since the enzyme has a heme prosthetic group, and since it catalyzes a peroxidase reaction, it was given the name chloroperoxidase (Hager et al., 1975). Recently, Edwards et al. (1980) have shown that the filamentous bluegreen alga *Scytonema hoffmanii* synthesizes a chlorinated cytotoxin (cyanbacterin I) which is lethal to at least 12 different species of bluegreen algae. Filamentous cyanophytes are now known to contain chloroperoxidase. This is the limit of the work in terrestrial systems, where Cl^- availability is crucial for the biosynthesis of the above secondary metabolites.

However, in the marine environment significant evolutionary pressures have led to the utilization of halide ions. Hager et al. (1980) have conducted a survey of over 900 marine animal and plant species for the presence of halogenated organic compounds. Approximately 25% of species tested had lipid extracts which contained greater than 10 μg of organic halogen per gram wet weight of tissue. The *Rhodophyta* (red algae) were found to be particularly rich in halogenated organic compounds. Also, most of these halocarbons were shown to be cytotoxic to microorganisms (Table 1). In all cases antimicrobial activity was found to be a function of the halogen content of these lipid extracts (Fig. 1). Therefore, it is likely that organisms in the marine environment have evolved mechanisms to detoxify these halogenated organic compounds through special metabolic pathways. Studies by Suida et al. (1975) with extracts of the red alga *Bonnemaisonia hamifera* have demonstrated the presence of a number of halogenated heptanones which arise by direct halogenation with a bromoperoxidase. By analogy with chloroperoxidase the reaction sequence in Scheme I explains the biosynthesis of brominated heptanones from 3-oxo-octanoic acid.

Hewson and Hager (1980) surveyed 72 different species of marine algae for



Scheme 1. Biosynthetic route for the synthesis of brominated heptanones.

Table 1. Organic halogen content and antimicrobial activity in marine animal and plant lipids

Phylum	Number of species examined	Average organic halogen content* Total halogen by direct assay (μmol/g)	Chlorine (μg/g)	Bromine (μg/g)	Chlorine plus bromine (μg/g)
Animal					
Porifera	71	0.55	14.1	19.4	33.5
Cnidaria	72	0.26	8.8	1.6	10.4
Clenophora	3	0.06	2.0	0.0	2.0
Platyhelminthes	4	0.14	5.0	0.3	5.3
Nemertina	4	0.22	8.5	0.0	8.5
Annelida	37	0.49	13.2	0.5	13.7
Mollusca	199	0.34	10.1	7.0	17.1
Arthropoda	97	0.18	6.9	0.4	7.3
Sipuncalida	4	0.11	4.0	0.0	4.0
Entoprocta	1	0.46	7.6	20.0	27.6
Ectoprocta	13	0.21	6.0	0.4	6.4
Chaetognatha	1	0.52	18.5	0.0	18.5
Echinodermata	83	0.30	9.4	4.0	13.4
Chordata	81	0.21	7.7	0.4	8.1
Animal summary	670	0.31	9.6	5.1	14.7
Plant					
Chlorophyta	31	0.11	3.7	0.3	4.0
Phactophyta	46	0.16	4.2	0.3	4.5
Rhodophyta	104	1.03	30.7	32.4	63.1
Cyanophyta	2	0.10	3.5	0.0	3.5
Tracheophyta	4	0.14	2.0	0.0	2.0
Angiosperms	2	0.13	2.3	5.0	7.3
Plant summary	189	0.64	19.8	19.1	38.9
All species summary	859	0.38	11.9	8.3	20.2

*Averages for chlorine and bromine are based on approximately 75% of the number of species collected.

the presence of bromoperoxidase, and 55 species were found to have high levels of this enzyme. The *Rhodophyta* were found to be better brominators, having the highest levels of bromoperoxidase and the greatest lipid halogen content. The *Phaeophyta* were the poorest halogenators. Besides containing a great variety of halogenated aliphatic compounds, marine organisms synthesize a multitude of halogenated aromatic compounds. For example, red algae of the

Table 1. (continued)

Phylum	Antimicrobial activity (% active species)				
	E. coli	*B. subtilis*	*S. cerevisiae*	*P. atrovenetum*	Active against at least one organism
Animal					
Porifera	18	32	13	17	37
Cnidaria	6	15	6	3	21
Clenophora	0	0	0	0	0
Platyhelminthes	0	0	0	25	25
Nemertina	0	0	0	0	0
Annelida	3	16	3	5	16
Mollusca	4	14	5	9	16
Arthropoda	0	1	0	0	1
Sipuncalida	0	0	0	0	0
Entoprocta	0	0	0	0	0
Ectoprocta	8	23	0	8	23
Chaetognatha	0	0	0	0	0
Echinodermata	0	17	27	16	43
Chordata	0	6	1	1	6
Animal summary	4	13	7	7	18
Plant					
Chlorophyta	0	10	0	0	10
Phactophyta	2	28	11	7	28
Rhodophyta	1	14	4	4	14
Cyanophyta	0	0	0	0	0
Tracheophyta	0	25	0	0	25
Angiosperms	50	50	0	50	100
Plant summary	2	17	5	4	18
All species summary	3	14	7	7	18

genus *Laurencia* synthesize a great variety of brominated and iodinated aromatic compounds (Izac and Sims, 1979) (Scheme II).

Several of these halogenated natural products are cytotoxic, and some of them resemble synthetic medicaments, insecticides, or pesticides. Since these halogenated natural products are synthesized by marine organisms, it follows that such organisms must have dehalogenation mechanisms to degrade them. Most halogenated synthetic compounds of industrial origin are regarded as