Descriptive Regional Oceanography

P. Tchernia
Laboratoire d'Oceanographie Physique, Museum National d 'Histoire Naturelle, Paris

Translated by D. Densmore

Pergamon Marine Series Volume 3

DESCRIPTIVE REGIONAL OCEANOGRAPHY

An Elementary Description of the Four Main Divisions of the World Ocean, of their Limits, Forms, Topography, Wind Systems, Climatology, Surface Circulation, and Hydrological Characteristics and Structure

by

P. TCHERNIA

Museum National d'Histoire Naturelle, Paris

PERGAMON PRESS

OXFORD · NEW YORK · TORONTO · SYDNEY · PARIS · FRANKFURT

U.K.	Pergamon Press Ltd., Headington Hill Hall, Oxford OX3 0BW, England
U.S.A.	Pergamon Press Inc., Maxwell House, Fairview Park, Elmsford, New York 10523, U.S.A.
CANADA	Pergamon of Canada, Suite 104, 150 Consumers Road, Willowdale, Ontario M2J 1P9, Canada
AUSTRALIA	Pergamon Press (Aust.) Pty. Ltd., P.O. Box 544, Potts Point, N.S.W. 2011, Australia
FRANCE	Pergamon Press SARL, 24 rue des Ecoles, 75240 Paris, Cedex 05, France
FEDERAL REPUBLIC OF GERMANY	Pergamon Press GmbH, 6242 Kronberg-Taunus, Pferdstrasse 1, Federal Republic of Germany

First edition 1980

British Library Cataloguing in Publication Data

Tchernia, P.
Descriptive regional oceanography.—(Pergamon marine series; vol. 3).
1. Oceanography
I. Title
551.4'6 GC11 78-40287

ISBN 0-08-020925-4 (Hardcover)
ISBN 0-08-020919-X (Flexicover)

Printed in Great Britain by A. Wheaton & Co. Ltd. Exeter.

Preface

THIS textbook on Regional Oceanography presents the substance of courses taught for nearly ten years to students of the University of Paris VI, candidates for the General Oceanography certificate. This curriculum, begun in 1967, required, as well as a course in dynamics of the ocean, a course on the physical and chemical properties of seawater, a course in marine biology, and another in geology.

To all the professors responsible for these courses it quickly became apparent that the students, whether physicists, biologists, chemists, or geologists, had only the most fragmentary knowledge of the oceans, and that it would be necessary to adapt the regulation and contents of the courses to this situation.

The author, bearing in mind the material taught by his colleagues, as well as the limited time (24–30 hours per year) allowed for his teaching, gave himself the task of presenting the known facts which appeared to him indispensable to an elementary description of the great divisions of the world ocean.

Being so limited, such an exposition, to be carried to conclusion in 30 hours of classes, called for strict selection among the existing information.

Throughout the description of the apparent diversity of the oceanic regions we have sought to express the idea of the unity of the ocean, considered on a planetary scale, and these proposals have been ordered in a manner which pairs cause with effect, whenever possible; in particular the relationship between atmosphere and ocean.

To maintain the character of a book of elementary introduction, we have made more use of the classical treatises of Schott, Sverdrup, Defant, and Dietrich than others, more recent, but still debatable and difficult to integrate into a synthesis of primary instruction.

To reduce the extent of the text we have omitted descriptions of epicontinental seas, even those of northwestern Europe, to center our study on the deep oceans, particularly those of the polar regions. Their role in the equilibrium of the world ocean is decisive, and in them three-quarters of the ocean waters acquire their characteristics.

For the reasons given on page 87 we have developed better the data relative to the Atlantic Ocean than those relative to the Pacific, even though that ocean represents 40% of the surface of the world ocean and the Atlantic only 25%.

We have attempted to graduate the difficulties of the text, and, for example, it is only at the end of the book (in Chapter 7 on the Pacific Ocean) that we complicate the clear and simple scheme of the system of equatorial currents established by Munk by the introduction of a description of the Cromwell Current. This book brings nothing to the real specialist in regional oceanography; to some of them it will seem even a bit obsolete.

The development of research and the instruction of oceanography since 1960 has led numerous teachers to publish introductory texts in oceanography. While some of these books apply themselves primarily to the fundamentals of physical oceanography (von Arx, 1962; McLellan, 1965; Groen, 1967), most cover the fundamentals of the diverse disciplines

of general oceanography (Williams, 1962; Ross, 1970; Weyl, 1970; Duxburry, 1971; Davis, 1972; Ingmanson and Wallace, 1973; Anikouchine and Sternberg, 1973; King, 1975; Thurman, 1975; Grant Gross (2nd edn.), 1977). None of these works gives the future oceanographer a succinct general description of the bounds and containment of the world ocean, the spatial variations of its structure, and its hydrological characteristics, and these basic understandings are, in our opinion, indispensable to any future oceanographer, whether physicist, biologist, chemist, or geologist.

Of them all, only the text on descriptive physical oceanography by Pickard devotes an important chapter to a discussion of the general circulation and hydrological structure of the great divisions of the world ocean, this chapter complementing those preceding which present a general survey of the physics of the ocean.

As these matters are at the University of Paris the object of the teaching noted above, we have been able to dedicate our whole course to the description of the world ocean.

For this we have, like Sverdrup and Pickard, chosen to study successively the four great subdivisions: Antarctic Ocean; Atlantic Ocean; Indian Ocean; Pacific Ocean. Each of these regions is described according to an identical plan:

(1) form, limits, dimensions, position on the globe;
(2) topography of the basin, sediments;
(3) distribution of centers of high and low atmospheric pressure, their seasonal variations, dominant prevailing winds, basic climatology;
(4) general surface circulation;
(5) hydrology:
    (a) distribution of surface temperatures and salinities;
    (b) hydrological structure: watermasses;
    (c) origin and formation of the different watermasses;
    (d) movements of these watermasses;
    (e) relation to the other oceans.

It is in the choice of the different parts of this plan, and after that their content—a choice for which the author is solely responsible—that the originality of this text lies, for the scientific information owes much to the classical treatises of Schott, Sverdrup, and Dietrich.

We have placed at the beginning of the work three short chapters giving the essential basic ideas relative to:

(1) the morphology of the Earth and the oceanic basins;
(2) the physical and chemical characteristics of seawater;
(3) the distribution of temperature, salinity, and density.

These elementary considerations are reduced here for the benefit of the isolated beginners to those I have considered necessary for the comprehension of certain subsequent developments. The beginners who feel the need for a more complete but simple introduction can find it in the first six chapters of the *Descriptive Physical Oceanography* of G. L. Pickard (second edition, Pergamon Press), the companion book to this work.

Given the elementary character of this book, we have not thought it useful to append bibliographical references. We give further on, however, the references of classical treatises which are the basic works in regional oceanography, then at the end of each chapter the references to the works, or parts of works, usually in English, where the reader will find to satisfy the interest which the reading of this text will have aroused.

Translator's Preface

WHEN I first met Paul Tchernia, in February of 1961 in Lisbon, I hardly anticipated being asked to be his translator sixteen years later. We were watchmates aboard the big ketch *Atlantis* out of Woods Hole on that cruise, the forerunner of a series of Franco–American assaults on the Mediterranean in winter. Numerous squalls and mistrals endured aboard the *A-boat*, *Calypso*, and *Jean Charcot* cemented the partnership, but I was apprehensive, nonetheless, at the author's act of faith in requesting me to undertake this work. I can do no better than to paraphrase Feodor Ostapoff, translator of Gunther Dietrich's classical *General Oceanography* (1963): "In preparing the English edition, more emphasis has been placed on an accurate reproduction of the ideas presented by the author than on elegance in style."

C. DANA DENSMORE

Suggestions for Further Reading

As we have indicated in the Preface, it was deemed useless to encumber this elementary textbook with bibliographic references. We shall content ourselves with offering a choice of works, mostly in English, in which the interested reader will find additional information.

The general basic treatises which are the indispensable tools of the oceanographer are given below, whereas at the end of each chapter we note the works or part of works which may be useful complements to the study of the subject covered in that chapter.

General Treatises

ARX, VON W. S., *An Introduction to Physical Oceanography*, Addison-Wesley, 1962.

DIETRICH, G., *General Oceanography*, an introduction with contributions by Kurt Kalle (translated in English from German by Feodor Ostapoff), 1963, Wiley, New York, 588 (2nd revised edn., in German, 1975).

DIETRICH, G. and ULRICH, J., *Atlas zur Ozeanographie*, Bibliogr. Inst. Mannheim, 1968.

DUXBURY, A. C., *The Earth and its Oceans*, Addison-Wesley, 1971, 381 pages.

FAIRBRIDGE, R. W., *The Encyclopedia of Oceanography*, Rheinhold, New York, 1966, 1021 pages.

LACOMBE, H., *Cours d'Océanographie Physique*, Gauthier-Villars éditor, Paris, 1965, 392 pages.

NEUMANN, G. and PIERSON, W. J., *Principles of Physical Oceanography*, Prentice-Hall, 1966.

PICKARD, G. L., *Descriptive Physical Oceanography*, 2nd edn., Pergamon Press, Oxford, 1975.

POND, S. and PICKARD, G. L., *Introduction to Dynamical Oceanography*, Pergamon Press, Oxford, 1978.

SVERDRUP, H. U., JOHNSON, M. W. and FLEMING, R. H., *The Oceans, their Physics, Chemistry and General Biology*, Prentice-Hall, New York, 1942, 1087 pages.

Acknowledgements

Reproduction of the following material is authorized through the courtesy of the publishers/copyright holders named herewith.

D. A. Ross, *Introduction to Oceanography:* Fig. 8.30, p. 284, Fig. 8.37, p. 293 (Appleton–Century–Crofts). [Figs. 7.1, 6.2.]

US Naval Hydrographic Office. HO pub. No. 705, 1957. *Oceanographic Atlas*, Part II, *Arctic.* Fig. 4, p. 7. [Fig. 5.20.]

A. Defant, *Physical Oceanography*, Vol. 1, 1961: Fig. 63, p. 152; Fig. 274, p. 600; Plate 4 (Bottom temperature) (Pergamon Press). [Figs. 5.29, 5.30.]

G. Pickard, *Descriptive Physical Oceanography*, 2nd edn: Fig. 24(a), p. 144 (Pergamon Press). [Fig. 5.32.]

Deep-sea Research, Vol. 6, No. 4, June 1960: Fig. 9, p. 279 (J. A. Knauss, Measurement of the Cromwell Current) (Pergamon Press). [Fig. 7.6.]

E. T. Degens and D. A. Ross, *Hot Brines and Recent Heavy Metal Deposits in the Red Sea:* Fig. 2(a), G. Siedler, p. 133 (Springer-Verlag). [Fig. 6.13.]

K. Wyrtki, *Naga Report*, Vol. 2, 1961: Plate 1, p. 164; Plate 4, p. 167 (Scripps Institution of Oceanography). [Figs. 7.5.]

(a) R. W. Fairbridge, *Encycl. of Oceanogr.* 1966: Fig. 1, p. 49; Fig. 20, p. 75; Fig. 2, p. 439; Fig. 11, p. 379; Fig. 7, p. 661; Fig. 12, p. 665; Fig. 5, p. 709; Fig. 6, p. 421. [Figs. 5.5, 5.8, 5.24, 6.3, 6.9, 7.4, 7.8, 7.9.] Dowden, Hutchinson and Ross Inc.

(b) R. W. Fairbridge, *Encycl. of Atmosph. Sc. and Astrogeology* 1967: Fig. 13, p. 1035. [Fig. 6.6] (Dowden, Hutchinson and Ross Inc.).

K. Wyrtki, *Oceanographic Atlas of the Internat. Indian Ocean Exped.*- National Science Foundation 1971: Plates 451, 452, 453, 439, 440, 441, 423, 424, 471, 472, 473, 399, 400, 401, 405, 406, 407, 411, 412, 413 and 83 [Figs. 6.12, 6.14, 6.16, 6.17, 6.19, 6.20, 6.21, 6.22.]

B. Haurwitz and J. M. Austin, *Climatology*, 1944: Plates IV and V. (McGraw-Hill). [Plates 2 and 3 and Fig. 6.5.]

C. O. D. Iselin, *Papers on Phys. Oceanogr. and Meteorol.* Vol. 4, no. 4, Figs. 3 and 4, 1936 [Fig. 5.15.]

G. Dietrich, *Gen. Oceanogr.* 1963: Figs. 205, 227, 125, 82 (John Wiley, Interscience) [Figs. 3.5, 5.19, 5.21, 5.22.]

H. H. Sverdrup, M. W. Johnson and R. H. Fleming, *The Oceans*, 1946, Fig. 158, p. 606; Fig. 164, p. 620; Fig. 160, p. 610; Fig. 165, p. 621; Fig. 163, p. 615; Fig. 5, p. 34; Fig. 6, p. 36; Fig. 184, p. 674; Fig. 187, p. 684; Fig. 176, p. 646; Fig. 168, p. 626; Fig. 36, p. 145; Fig. 209(A), p. 740; Fig. 209(B), p. 741; Fig. 205, p. 727; Fig. 209(B), p.741. (Prentice Hall) [Fig. 4.1, 4.13, 4.15, 4.20, 5.6, 5.7, 5.13, 5.16, 5.17, 5.27, 5.37, 5.38, 5.39, 5.43, 7.7, 7.13.]

G. Wüst in Neumann and Pierson, *Principles of Physical Oceanography*, 1966: Fig. 14.37, p. 466; Fig. 14.38, p. 467 (Prentice-Hall). [Figs. 5.45.]

Georg Wüst, *Wiss Ergeb. der Deutschen Atlant. Expedition auf dem Forschungs und Vermessungsschiff "Meteor" 1925–1927* Band VI, Erster Teil 1936; Beilage XXIX, XXIV, XXIII, XXVII (Walter de Gruyter and Co). [Figs. 5.33, 5.40, 5.41, 5.42.]

W. Düing, *The Monsoon Regime of the Currents in the Indian Ocean*, 1970: Fig. 9, p. 22; Fig. 11, p. 24 (University Press of Hawaii). [Fig. 6–9.]

(Deutsches Hydrographisches Institut) *Monatskarten fur den Indischen Ozean. Oberflaschenstromung February and August.*, Publ. No. 2422, 1960. [Fig. 6.7, 6.8.]

G. Schott, *Geographie des Indischen und Stillen Ozeans*, 1935: Tafel XIII, XIV, XIX, XX, XXI, XXII, XXIII, XXVII, XXIX, XX, *Geographie des Atlantischen Ozean*, 1944: Tafel XI, XII, XIV, XVI, XVII, XXII (C. Boysen). [Plates 4–19.]

W. S. Von Arx, *Introduction to Physical Oceanography*, 1962: Fig. 2.1, p. 20. Addison-Wesley. [Fig. 5.14.]

B. Heezen *et al.*, *The Floors of the Ocean:* I, *North Atlantic:* Plate 22(I), Geological Society of America, April 1959, Special Paper No. 65. [Fig. 5.4.]

Encyclopaedia Britannica, 14th edn, 1964. Fig. 1, Vol. 16, p. 682; Fig. 5, Vol. 16, p. 689 (Encyclopaedia Britannica Inc.). [Plate 1 and Fig. 1.1.]

G. E. R. Deacon, *Discovery Report*, 1937. Vol. XV, Plates XLIV, XIX, XX, XXI (Institute of Oceanographic Sciences, England). [Figs. 4.12, 4.18.]

W. Munk, On the Wind-Driven Ocean Circulation. Journal of Meteorology, VII, 2, 1950. (American Meteorological Society). [Fig. 5.12.]

Zenkevitch, *Biology of the Seas of the USSR*, Fig. 2, p. 31. G. Allen and Unwin [Fig. 5.25]

C. Ramage, *Barnes Annual Review*, No. 7, 1969: Fig. 1, p. 12 (George Allen & Unwin). [Fig. 6.4.]

J. Bartholomew & Sons, Edinburgh. [Fig. 1.3.]

Woods Hole Oceanographic Institution and H. Stommel. [Fig. 1.4.]

M. Ewing, Ocean Sciences, US Naval Inst., 1964. [Fig. 1.5.]

Am. Geogr. Soc., Map of Antarctica, 1970. [Fig. 4.2.]

John Swallow *et al.*, *Deep Sea Res.*, Vol. 13, Fig. 3, p. 829 (Pergamon edn., Oxford). [Fig. 6.10.]

Service Hydrographique de la Marine—Instructions Nautiques, Vol. K-VI, Pl. 1, Paris, 1966. [Fig. 7.3.]

Panfilova *Oceanology*, Vol. 7, 1967. [Fig. 7.14.]

Kuenen, Realm of Water, Fig. 79, John Wiley, 1955 [Fig. 4.16.]

Units and Symbols

1. Units

LENGTH

Mile: the nautical unit of linear measure is the international standard nautical mile, defined as approximately 1 minute of arc of any great circle route on the Earth's surface. The word "mile" in this book always means "nautical mile" (n.m.). Its equivalent in the metric or c.g.s. system is 1,852 meters (1 kilometer is 0.540 n.m.).

Fathom: 1 fathom = 6 feet = 1.8285 meters.

SPEED

Knot: the nautical unit for speed is the knot which is the equivalent for 1 nautical mile per hour.

1 knot = 51.5 centimeters per second.

1 kilometer per hour = 27.8 cm per second.

VOLUME

1 milliliter (1 ml) = 1 cubic centimeter (cm^3).

1 liter (1 l) = 1000 milliliters.

1 cubic meter (m^3) = 1000 liters = 1×10^3 liters.

1 cubic kilometer (km^3) = 1×10^9 liters.

Volume Transport

In physical oceanography the most commonly used unit for volume transport is one million cubic meters per second = 1×10^6 m^3/s.

PRESSURE

1 atmosphere = 1.013 bar = 1013 millibars = 760 millimeters of mercury at 0°C.

1 millibar = 1 mb = 1000 baryes = 1000 dyn/cm^2.

1 mb = 0.750062 mmHg.

1 mmHg = 1.33322 mb.

(Practically 3 mmHg = 4 mb.)

2. Symbols

Temperature (on the Celsius scale) = T.

Potential temperature = θ (see page 28).

Salinity = $S‰$ = total amount of dissolved salts, in grams, contained in one kilogram of seawater (one kilogram of seawater is always less than 1 liter).

Density: Sigma-tee = σ_t = density at the atmospheric pressure.

Sigma-theta = σ_θ = potential density = density at the potential temperature.

(For the use of the word "density" in physical oceanography, cf. Pickard (*Descriptive Physical Oceanography*, 2nd edn., Pergamon), Chapter 3, pp. 14–26.)

Contents

PART ONE

Introductory