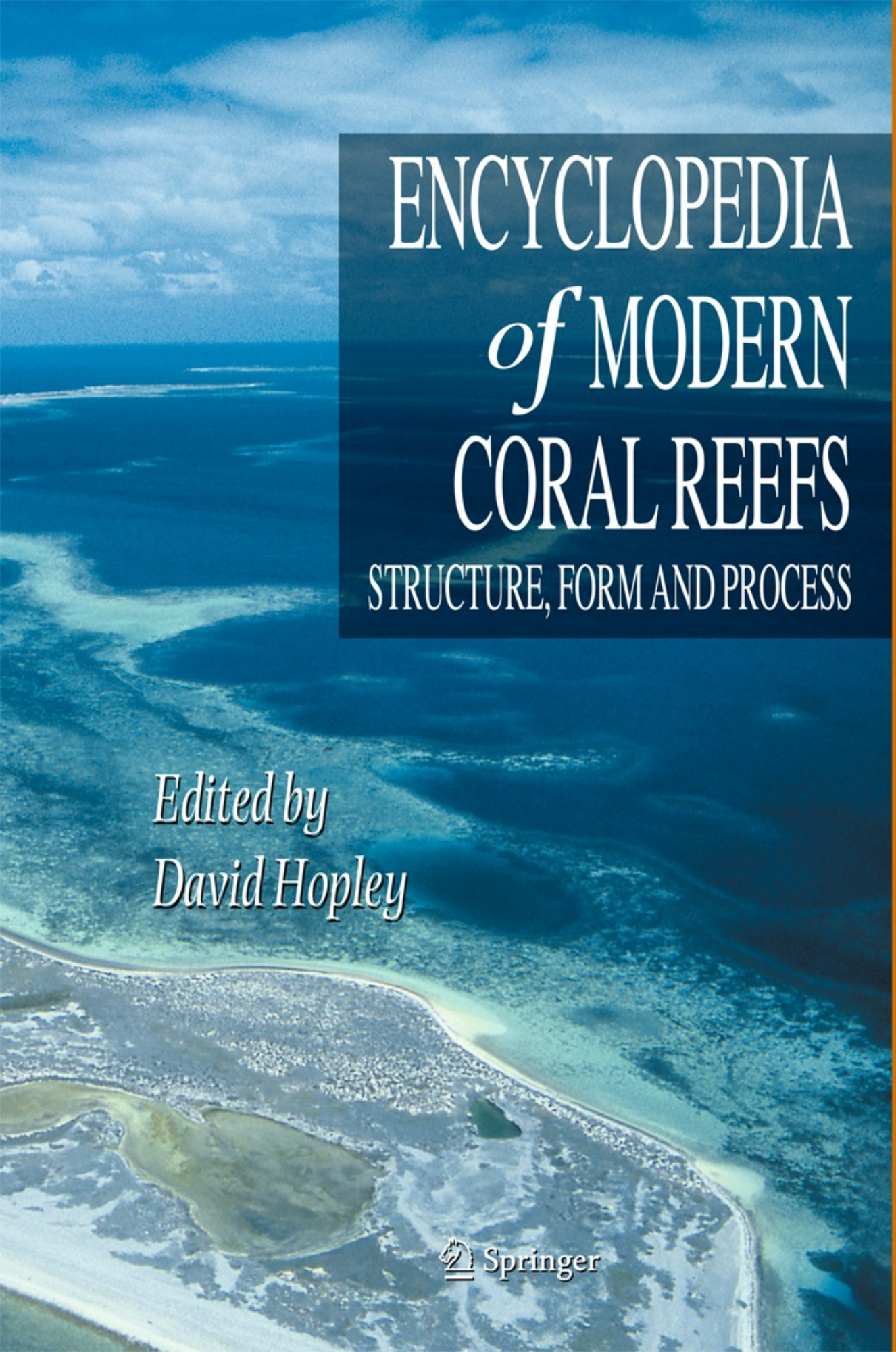

ENCYCLOPEDIA of MODERN CORAL REEFS

STRUCTURE, FORM AND PROCESS

Edited by
David Hopley

Springer

ENCYCLOPEDIA of EARTH SCIENCES SERIES

ENCYCLOPEDIA *of* MODERN CORAL REEFS

Structure, Form and Process

Encyclopedia of Earth Sciences Series

ENCYCLOPEDIA OF MODERN CORAL REEFS – STRUCTURE, FORM AND PROCESS

Volume Editor
David Hopley is Professor Emeritus in the School of Earth and Environmental Science at James Cook University, Townsville, Queensland, Australia, where he has worked since 1965. He has an M.A. from the University of Manchester and Ph.D. from James Cook University. His initial research into Holocene sea levels and tropical landforms quickly focused on the evolution of coral reefs, reflecting the importance of the Great Barrier Reef to his home institution. Experience with coral reefs extends to many parts of the world including Australia, Barbados, India, Indonesia, Maldives, Papua New Guinea, Rodrigues and Thailand. He has authored and edited almost 200 scientific publications. Amongst numerous awards have been the J.P. Thomson silver medal from the Royal Geographical Society of Australasia (1984) and Life Membership of PACON International (1992).

Aims of the Series
The *Encyclopedia of Earth Sciences Series* provides comprehensive and authoritative coverage of all the main areas in the Earth Sciences. Each volume comprises a focused and carefully chosen collection of contributions from leading names in the subject, with copious illustrations and reference lists.

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About the Series Editor
Professor Charles W. Finkl has edited and/or contributed to more than eight volumes in the *Encyclopedia of Earth Sciences Series*. For the past 25 years, he has been the Executive Director of the Coastal Education & Research Foundation and Editor-in-Chief of the international *Journal of Coastal Research*. In addition to these duties, he is Research Professor at Florida Atlantic University in Boca Raton, Florida, USA. He is a graduate of the University of Western Australia (Perth) and previously worked for a wholly owned Australian subsidiary of the International Nickel Company of Canada (INCO). During his career, he acquired field experience in Australia, the Caribbean, South America, southwest Pacific islands, southern Africa, Western Europe, and the Pacific Northwest, Midwest, and Southeast USA.

Founding Series Editor
Professor Rhodes W. Fairbridge (deceased) has edited more than 24 encyclopedias in the Earth Sciences Series. During his career, he has worked as a petroleum geologist in the Middle East and been a World War II intelligence officer in the southwest Pacific and led expeditions to the Sahara, Arctic Canada, Arctic Scandinavia, Brazil, and New Guinea. He was Emeritus Professor of Geology at Columbia University and was affiliated with the Goddard Institute for Space Studies.

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DAVID HOPLEY
James Cook University
Townsville
Australia

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Dedication to Rhodes Fairbridge
(21st May 1914 to 8th November 2006)

A tribute to Rhodes W. Fairbridge in this Encyclopedia of Modern Coral Reefs could not be more appropriate. He was the founding editor of the *Encyclopedia of Earth Sciences Series*, launched in 1966 and continued as Series Editor and for a number of volumes, as Editor-in-Chief, until he passed away in 2006. The series consists of almost 30 volumes and reflects Rhodes' holistic knowledge of the earth, ocean and atmospheric sciences.

Although Rhodes spent his career at Columbia University in New York, he was born in Pinjarra, Western Australia. He graduated with degrees in geology from Queens University, Canada and Oxford University U.K. before receiving a DSc. from the University of Western Australia in 1942. During the war he served in the Royal Australian Air Force where, with friend and colleague Curt Teichert he became interested in aerial photography of coral reefs, initially from a military point of view but subsequently as an aid to interpreting the surficial features of reefs, his first study site being Low Isles on the Great Barrier Reef, the location of the 1928-29 Royal Society Expedition led by Sir Maurice Yonge.

From this time on Rhodes' research interests, to 1955 at the University of Western Australia, then at Columbia University, New York were intimately related to the topics around which this encyclopedia revolves. His interests in coastal geomorphology and especially in past sea level features were promoted by the spectacular calcarenite coastline of south-western Australia. Features of climate change are also prominent in arid climates, such as most of Western Australia, and this too became a focus of Rhodes' interests.

It is not surprising that Rhodes took a very active interest in the newly developing techniques of radiometric dating. In particular they allowed for the quantification of Quaternary events, particularly sea level change. He was the first to put together a sea level curve for the Holocene and, although developed from different locations and not applicable to all sites, the Fairbridge sea level curve did much to promote coastal studies. This was no more so than at the 1969 Paris INQUA meeting where the gathering of the Sea Level Commission and the associated field excursion around the Atlantic coast of France saw the emergence of numerous ideas which were developed over the next few decades and applied to the many areas from where the INQUA delegates had come.

Rhodes was a scientist with extremely wide vision with a natural curiosity which saw him following up explanations across different fields of science. Sea level change led him into oceanography and climate change which he examined at a broad geological timescale. He was ahead of his time in accepting the Milankovitch theory directing his interests into the planetary sciences. When global climate change became a focus of discussion no-one was in a better position than Rhodes to put some of the initial ideas into a more reasonable context pointing out that the earth's climate has always been changing and that data was needed to evaluate human contribution to global warming. Again he was predicting the future direction of research although his conclusion that "Whatever the present trend, the last word will always be political", seems especially prognostic!

The ideas of Rhodes Fairbridge permeate through this encyclopedia which I believe is a most appropriate volume to pay tribute to his contributions to science in general and to the Earth Sciences Encyclopedia Series in particular. I am especially honoured to be able to make this dedication as Rhodes, who always retained his Australian citizenship, had a strong influence on the early part of my career. My honours and Masters theses were on the coast of North Wales and reference to Rhodes' sea level work was inevitable and even more so for my 1970 PhD. on the coast and islands of North Queensland. However, by

Field trip on the coast of northern France at the 1969 INQUA conference (left David Hopley, right Rhodes Fairbridge)

that time I had not only met Rhodes (initially when he passed through Townsville) but had spent more than 3 weeks with him on the second half of his expedition to the islands east of New Guinea (Misima, Rossell and Louisiades etc.). He had recognised that my experience with reefs (coming from the UK) was minimal and saw this as an ideal opportunity for "field tutoring". It certainly paved my way into reef research. Also on the expedition was Rhodes' charming wife Dolores (then working for the Carnegie Museum) who did much to lighten what at times were some very dark days (including the edge of a tropical cyclone). This included suggesting that whilst at sea, the men of the expedition wear lap-laps!

More time was spent with Rhodes a few months later at the 1969 Paris INQUA meeting. We were also together on the field trip around the French coast from Sangatte to Les Sables d'Olonne, where I think Rhodes' breadth of knowledge and respect from fellow Quaternary scientists really shone through. Subsequently, apart from a couple of days with Rhodes and Dolores at their Long Island home at Amagansett, contact for me unfortunately has only been through occasional sea level meetings and committees.

Rhodes Fairbridge has left many testaments by which he will be remembered. None, I believe, are more appropriate than the *Encyclopedia of Earth Sciences Series*. However, it is a privilege to have this dedication to such a prominent twentieth century 'Man of Science' especially in this specific encyclopedia on coral reefs.

David Hopley
Editor-in-Chief

Contents

Contributors

Elizabeth Abbey
School of Geosciences
The University of Sydney
Sydney, NSW 2006
Australia
elizabeth.abbey@sydney.edu.au

Nerilie J. Abram
British Antarctic Survey
Madingley Road
Cambridge, CB3 0ET
UK
NABR@bas.ac.uk

Serge Andréfouët
Centre IRD
Institut de Recherche pour le Développement (I.R.D.)
UMR 227 - CoRéUs (Communautés Récifales et Usages)
101 Promenade Roger Laroque
Anse Vata, Noumea BP A5 - 98848
New Caledonia
serge.andrefouet@ird.fr

Markus Aretz
LMTG (OMP)
Université de Toulouse (UPS)
14 Avenue Edouard Belin
Toulouse, 31400
France
markus.aretz@lmtg.obs-mip.fr

Richard B. Aronson
Department of Biological Sciences
Florida Institute of Technology
150 West University Boulevard
Melbourne, FL 32901
USA
raronson@fit.edu

Marlin J. Atkinson
School of Ocean and Earth Science and Technology
Hawaii Institute of Marine Biology
University of Hawaii
P.O. Box 1346
Kaneohe, Hawaii 96744
USA
mja@hawaii.edu

Andrew C. Baker
Division of Marine Biology and Fisheries
Rosenstiel School of Marine and Atmospheric Science
University of Miami
4600 Rickenbacker Cswy
Miami, FL 33149
USA
abaker@rsmas.miami.edu

Todd R. Barber
The Reef Ball Foundation
3305 Edwards Court
Atlanta, GA 27858
USA
reefball@reefball.com

Robin J. Beaman
School of Earth and Environmental Sciences
James Cook University
P.O. Box 6811
Cairns, QLD 4870
Australia
robin.beaman@jcu.edu.au

Naomi Biribo
School of Environmental Science
University of Wollongong
NSW 2522
Australia
nb766@uow.edu.au

Paul Blanchon
Reef Systems Unit
Institute of Marine Sciences and Limnology
National Autonomous University of Mexico
Ap Postal 1152
Cancun, 77500
Mexico
blanchons@gmail.com

James Bowen
Environmental Science & Management
Southern Cross University
Lismore, NSW 2480
Australia
jamesbowen@exemail.com.au

Juan C. Braga
Departamento de Estratigrafía y Paleontogía
Universidad de Granada
Campus de Fuentenueva
18071 Granada
Spain
jbraga@ugr.es

John C. Brock
Coastal and Marine Geology Program
U.S. Geological Survey
915-B National Center
12201 Sunrise Valley Drive
Reston, VA 20192
USA
jbrock@usgs.gov

Barbara E. Brown
School of Biology
University of Newcastle
Newcastle upon Tyne, NE1 7RU
UK
ProfBarbaraBrown@aol.com

Helmut Brückner
Faculty of Geography
Institute of Geography University of Marburg
Deutschhausstr. 10
35032 Marburg
Germany
h.brueckner@uni-koeln.de

Lauretta Burke
World Resources Institute
10 G Street NE Suite 800
Washington, DC 20002
USA
Lauretta@wri.org

Maria Byrne
Developmental and Marine Biology, Anatomy and Histology, F13
One Tree Island Research Station
University of Sydney
Sydney, NSW 2006
Australia
mbyrne@anatomy.usyd.edu.au

Guy Cabioch
IPSL/LOCEAN UPMC/CNRS/IRD/MNHN
UMR LOCEAN
IRD (Institut de Recherche pour le Développement),
Centre d'Ile de France
32 Avenue Henri Varagnat
Bondy, CEDEX 93143
France
guy.cabioch@ird.fr

Lindsay B. Collins
Department of Applied Geology
Curtin University of Technology
GPO Box U1987
Perth, WA 6845
Australia
L.Collins@curtin.edu.au

Paul Copper
Department of Earth Sciences
Laurentian University
Ramsey Lake Rd
Sudbury, ON P3E 2C6
Canada
pcopper@laurentian.ca

Jorge Cortés
Centro de Investigación en Ciencias del Mar y Limnología (CIMAR)
Universidad de Costa Rica
San José, San Pedro de Montes de Oca, 11501-2060
Costa Rica
jorge.cortes@ucr.ac.cr

Roger J. Cuffey
Professor Emeritus of Paleontology
Department of Geosciences
Pennsylvania State University
412 Deike Bldg. (N. Burrowes Rd.)
University Park (State College), PA 16802
USA
rcuffey@psu.edu

Peter J. Davies
School of Geosciences
University of Sydney
Camperdown
Sydney, NSW 2006
Australia
taffiespeter@gmail.com

Jon C. Day
Ecosystem Conservation and Sustainable Use
Great Barrier Reef Marine Park Authority (GBRMPA)
P.O. Box 1379
Townsville, QLD 4810
Australia
j.day@gbrmpa.gov.au

Elizabeth A. Dinsdale
Biology Department
San Diego State University
5500 Campanile Drive
San Diego, CA 92182
USA
Elizabeth_dinsdale@hotmail.com

David J. Dixon
Independent Oceanographer/Geomatics Surveyor
2 Cleveland Villa, Paynters lane
Illogan, Redruth, Cornwall, TR16 4DT
UK
mypostemail-coraltides@yahoo.co.uk

Richard E. Dodge
NSU Oceanographic Center
National Coral Reef Institute
8000 North Ocean Drive
Dania Beach, FL 33004
USA
dodge@nova.edu

Terry Done
Australian Institute of Marine Science
PMB 3 Townsville MC, QLD 4810
Australia
t.done@aims.gov.au

Edward Drew
21 Bishop Street
Belgian Gardens, Townsville, QLD Q 4810
Australia
edrew1@austarnet.com.au

Norman C. Duke
School of Biological Sciences
University of Queensland
St Lucia Campus
Brisbane, QLD 4072
Australia
n.duke@uq.edu.au

Evan Edinger
Departments of Geography, of Biology, and of Earth Sciences
Memorial University of Newfoundland
St. John's Newfoundland and Labrador A1B 3X9
Canada
eedinger@mun.ca

Paul Enos
Department of Geology
University of Kansas
1475 Jayhawk Blvd., Room 120
Lawrence, KS 66045-7613
USA
enos@ku.edu

Katharina Fabricius
Australian Institute of Marine Science
PMB 3
Townsville, QLD 4810
Australia
k.fabricius@aims.gov.au

Stewart Fallon
Research School of Earth Sciences
Australian National University
Canberra, ACT 200
Australia
stewart.fallon@anu.edu.au

Joshua S. Feingold
Oceanographic Center
Nova Southeastern University
8000 North Ocean Drive
Dania Beach, FL 33004
USA
joshua@nova.edu

Charles Finkl
Department of Geosciences
Florida Atlantic University
Coastal Planning & Engineering, Inc., CPE Coastal Geology & Geomatics
2481 N.W. Boca Raton Boulevard
Boca Raton, FL 33431
USA
Cfinkl@coastalplanning.net

Elizabeth Flint
Hawaii and Pacific National Wildlife Refuges and Marine National Monuments
U.S. Fish and Wildlife Service
Box 50167, 300 Ala Moana Blvd.
Honolulu, HI 96744
USA

Peter Flood
Earth Sciences Building CO2
University of New England
Armidale, NSW 2351
Australia
pflood@une.edu.au

Murray Ford
School of Geography, Geology and Environmental Science
The University of Auckland
Private Bag 92019
Auckland
New Zealand
and
University of Hawaii
Sea Grant College Program
College of the Marshall Islands
P.O. Box 1258
Majuro, MH, 96960
Republic of Marshall Islands
murray.ford@auckland.ac.nz
murrayrf@hawaii.edu

André Freiwald
Senckenberg Meeresgeologie
Südstrand 40
26382 Wilhelmshaven
Germany
andre.freiwald@senckenberg.de

Cliff Frohlich
John A. and Katherine G. Jackson School of Geosciences
Institute for Geophysics
The University of Texas at Austin
10100 Burnet Rd (R2200)
Austin, TX 78758-4445
USA
cliff@ig.utexas.edu

Miles J. Furnas
Australian Institute of Marine Science
PMB No. 3
Townsville MC, QLD 4810
Australia
m.furnas@aims.gov.au

Michael K. Gagan
Research School of Earth Sciences
The Australian National University
Canberra, ACT 0200
Australia
michael.gagan@anu.edu.au

Jörn Geister
Earth Science Department
Naturhistorisches Museum Bern
University of Bern
Bernastrasse 15
3005 Bern
Switzerland
geister@geo.unibe.ch

Amatzia Genin
The Interuniversity Institute of Marine Sciences
POB 469
Eilat, 88103
Israel
and
Department of Evolution, Systematics & Ecology
The Hebrew University of Jerusalem
Jerusalem, 91904
Israel
amatzia@vms.huji.ac.il

Robert N. Ginsburg
Division of Marine Geology and Geophysics
Rosenstiel School of Marine and Atmospheric Science
University of Miami RSMAS/MGG
4600 Rickenbacker Cswy
Miami, FL 33149
USA
rginsburg@rsmas.miami.edu

Eberhard Gischler
Institut für Geowissenschaften
Goethe-Universität
Altenhoeferallee 1
60438 Frankfurt am Main
Germany
gischler@em.uni-frankfurt.de

William B. Goodwin
Florida Keys National Marine Sanctuary
P.O. Box 1083, Key Largo, Fl 33037
USA
bill.goodwin@noaa.gov

Michael R. Gourlay
School of Civil Engineering
The University of Queensland
Brisbane, QLD 4072
Australia
m.gourlay@uq.edu.au

Benjamin J. Greenstein
Department of Geology
Cornell College
600 First Street SW
Mount Vernon, IO 52314
USA
bgreenstein@cornellcollege.edu

Richard W. Grigg
Emeritus Professor of Oceanography
Department of Oceanography
University of Hawaii
1000 Pope Road
Honolulu, HI 96822
USA
rgrigg@soest.hawaii.edu

Pamela Hallock
College of Marine Science
University of South Florida
140 Seventh Ave. S.
St. Petersburg, FL 33701-5016
USA
pmuller@marine.usf.edu

Nick Harvey
Faculty of Humanities and Social Sciences
The University of Adelaide
Adelaide, SA 5005
Australia
nick.harvey@adelaide.edu.au

Clifford J. Hearn
Working Science Consultancies, LLC
200, 2nd Avenue South, Suite 519
St Petersburg, FL 33701
USA
clifford_hearn@yahoo.com

Harold Heatwole
Department of Biology
North Caroline State University
140 David Clark Labs
Raleigh, NC 27965-7617
USA
harold_heatwole@ncsu.edu

Kevin P. Helmle
Atlantic Oceanographic and Meteorological Laboratory
National Oceanic and Atmospheric Administration
4301 Rickenbacker Causeway
Miami, FL 33149
USA
and
Oceanographic Center
National Coral Reef Institute
Nova Southeastern University
8000 North Ocean Drive
Dania Beach, FL 33004
USA
kevin.helmle@noaa.gov
kevinh@nova.edu

Chuki Hongo
Department of Earth and Planetary Science
University of Tokyo
Hongo, Tokyo 113-0033
Japan
c-hongo@eps.s.u-tokyo.ac.jp

David Hopley
School of Earth and Environmental Sciences
James Cook University
Townsville, QLD 4811
Australia
david.hopley@bigpond.com

Matthew J. Hornbach
John A. and Katherine G. Jackson School of Geosciences
Institute for Geophysics
University of Texas at Austin
Austin, TX 78758-4445
USA
matth@utig.ig.utexas.edu

Peter Houk
Pacific Marine Resources Institute, Inc.
Saipan, MP
USA
and
CNMI Marine Monitoring Program
CNMI Division of Environmental Quality
P.O. Box 501304
Saipan, MP 96950
USA
peterhouk@pacmares.com
peterhouk@gmail.com

Dennis Hubbard
Department of Geology
Oberlin College
Oberlin, OH 44074
USA
dennis.hubbard@oberlin.edu

J. Harold Hudson
Reef Tech Inc.
8325 SW 68th Street
Miami, FL 33143
USA
hhudson3@bellsouth.net

Pat Hutchings
The Australian Museum
6 College Street
Sydney, NSW 2010
Australia
Pat.Hutchings@austmus.gov.au

Hironobu Kan
Graduate School of Education/Graduate School of Natural Sciences
Okayama University
3-1-1 Tsushima Naka
Kita-ku, Okayama, 700-8530
Japan
kan@cc.okayama-u.ac.jp

Hajime Kayanne
Department of Earth and Planetary Science
University of Tokyo
7-3-1 Hongo
Bunkyo- ku, Tokyo 113-0033
Japan
kayanne@eps.s.u-tokyo.ac.jp

Paul Kench
The School of Environment
The University of Auckland
Private Bag, 92019
Auckland
New Zealand
p.kench@auckland.ac.nz

Christopher G. St. C. Kendall
Distinguished Professor Emeritus of Geological Sciences
University of South Carolina
Columbia, SC 29208
USA
kendall@geol.sc.edu

Ruy K. P. Kikuchi
Geophysics and Geology Research Center
Geosciences Institute
Federal University of Bahia
Rua Barão de Jeremoabo s/n, Campus Universitário de Ondina
Bahia, Salvador 40170-115
Brazil
kikuchi@ufba.br

Joan A. Kleypas
Interdisciplinary Studies Program & Climate & Global Dynamics Division
Institute for the Study of Society and Environment
National Center for Atmospheric Research
P.O. Box 3000
Boulder, CO 80307-3000
USA
kleypas@ucar.edu

Jason Krumholz
Graduate School of Oceanography
University of Rhode Island
South Ferry Rd.
Narragansett, RI O2882
USA
jkrumholz@gso.uri.edu

Jacques Laborel
UMR DIMAR
Université de la Méditerranée, Faculte des Sci. de Luminy
13288 Marseille Cedex 9
France
rutabaga@pacwan.fr

Kurt Lambeck
Research School of Earth Sciences
The Australian National University
Canberra, ACT 0200
Australia
kurt.lambeck@anu.edu.au

José H. Leal
The Bailey-Matthews Shell Museum
P.O. Box 1580, 3075 Sanibel-Captiva Road
Sanibel, FL 33957
USA
jleal@shellmuseum.org

Zelinda M. A. N. Leão
Geophysics and Geology Research Center
Geosciences Institute
Federal University of Bahia
Rua Barão de Jeremoabo s/n,
Campus Universitário de Ondina
Bahia, Salvador 40170-115
Brazil
zelinda@ufba.br

Barbara H. Lidz
US Department of the Interior
U.S. Geological Survey, Center for Coastal & Regional Marine Studies
600 4th Street South
St. Petersburg, FL 33701-4802
USA
blidz@usgs.gov

Diane S. Littler
Department of Botany, MRC 166
National Museum of Natural History
Smithsonian Institution
P.O. Box 37012
Washington, DC 20013-7012
USA
littlerd@si.edu

Mark M. Littler
Department of Botany, MRC 166
National Museum of Natural History
Smithsonian Institution
P.O. Box 37012
Washington, DC 20013-7012
USA
littlerm@si.edu

Alan Logan
Centre for Coastal Studies
University of New Brunswick
P.O. Box 5050
Saint John, N.B. E2L 4L5
Canada
logan@unbsj.ca

Janice M. Lough
Australian Institute of Marine Science
PMB 3
Townsville MC, QLD 4810
Australia
j.lough@aims.gov.au

Edward Lovell
Faculty of Science and Technology and Environment
School of Marine Studies
University of the South Pacific
PMB, Laucala Campus
Suva
Fiji
lovell_e@usp.ac.fj

Alexis Lugo-Fernández
Minerals Management Service, Physical Sciences Unit (MS 5433), Gulf of Mexico OCS Region
1201 Elmwood Parkway Blvd.
New Orleans, LA 70123-2394
USA
alexis.lugo.fernandez@mms.gov

Ian G. Macintyre
Smithsonian Institution
National Museum of Natural History
P.O. Box 37012
Washington, WA 20013-7012
USA
macintyr@si.edu

Joshua Madin
Department of Biological Sciences
Macquarie University
Sydney, NSW 2109
Australia
jmadin@bio.mq.edu.au

James E. Maragos
Hawaii and Pacific National Wildlife Refuges and Marine National Monuments
U.S. Fish and Wildlife Service
Box 50167, 300 Ala Moana Blvd.
Honolulu, HI 96744
USA
jim_maragos@fws.gov

Eric G. Matson
Australian Institute of Marine Science
PMB 3 Mail Centre
Townsville, QLD 4810
Australia
e.matson@aims.gov.au

Barbara Maxfield
Hawaii and Pacific National Wildlife Refuges and Marine National Monuments
U.S. Fish and Wildlife Service
300 Ala Moana Blvd.
Box 50167, Honolulu, HI 96744
USA
barbara_maxfield@fws.gov

Helen V. McGregor
School of Earth and Environmental Sciences
University of Wollongong
Northfields Avenue
Wollongong, NSW 2522
Australia
mcgregor@uni-bremen.de

Sue J. McLaren
Department of Geography
University of Leicester
University Road
Leicester, LE1 7RH
UK
sjm11@le.ac.uk

Roger McLean
School of Physical, Environmental and Mathematical Sciences
Australian Defence Force Academy
University of New South Wales
Canberra, ACT 2600
Australia
roger.mclean@adfa.edu.au

Mark D. Merlin
Biology Program
University of Hawaii at Mānoa
Dean Hall
Manoa, Honolulu, HI 96822
USA
merlin@hawaii.edu

Ian Miller
Australian Institute of Marine Science
PMB 3
Townsville MC, QLD 4810
Australia
i.miller@aims.gov.au

Lucien F. Montaggioni
Department of Earth and Environmental Sciences
Centre de Sédimentologie-Paléontologie
University of Provence, Research Unit EA 4234
3, Place Victor Hugo
13331 Marseille Cedex 3
France
Lucien.Montaggioni@univ-provence.fr

R. John Morrison
School of Earth and Environmental Sciences
University of Wollongong
Northfields Avenue
Wollongong, NSW 2522
Australia
johnm@uow.edu.au

Thaddeus Murdoch
Bermuda Reef Ecosystem Assessment and Mapping Programme (BREAM)
Bermuda Zoological Society
P.O. Box 145
Flatts, FL-BX
Bermuda
tjmurdoch@gov.bm

A. Conrad Neuman
Curriculum in Marine Sciences
University of North Carolina
12-7 Venable Hall
Chapel Hill, NC 27514
USA
ANeumann@email.unc.edu

Jonathan Nott
School of Earth and Environmental Sciences
James Cook University
P.O. Box 6811
Cairns, QLD 4870
Australia
jonathan.nott@jcu.edu.au

David Obura
CORDIO East Africa
P.O. Box 10135, #9 Kibaki Flats, Kenyatta Beach, Bamburi Beach
Mombasa, 80101
Kenya
dobura@cordioea.org

Shigeru Ohde
Department of Chemistry, Biology, and Marine Science
University of the Ryukyus, College of Science
1 Senbaru, Nishihara-cho
Okinawa, 903-0213
Japan
sohde@sci.u-ryukyu.ac.jp

Yoko Ota
Department of Geological Sciences
National Taiwan University
106, No. 1, Sect. 4, Roosevelt Road
Taipei
Taiwan
and
Yokohama National University (Professor Emeritus)
2-11-13-201, Minamisenzoku
Otaku, Tokyo
Japan
yokoota@ntu.edu.tw

Monica Palaseanu-Lovejoy
Jacobs Technology
U.S. Geological Survey, Florida Integrated Science Center
600 4th Street South
St. Petersburg, FL 33701
USA
mpal@usgs.gov

John M. Pandolfi
ARC Centre of Excellence in Coral Reef Studies
The Centre for Marine Studies and School of Earth Sciences
The University of Queensland
60 Gehrmann Laboratories
Brisbane, QLD 4072
Australia
j.pandolfi@uq.edu.au

Claire B. Paris-Limouzy
Rosenstiel School of Marine & Atmospheric Science
Division of Applied Marine Physics
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149
USA
cparis@rsmas.miami.edu

Kevin E. Parnell
School of Earth and Environmental Sciences
James Cook University
Townsville, QLD 4811
Australia
kevin.parnell@jcu.edu.au

Mark R. Patterson
Virginia Institute of Marine Science
College of William & Mary
P.O. Box 1346
Gloucester Point, VA 23062-1346
USA
mrp@vims.edu

Christine Perrin
LMTG
Université Toulouse 3
14, Av. Edouard Bélin
31400 Toulouse
France
and
Muséum National d'Histoire Naturelle
UMR 7207 du CNRS CR2P
8 Rue Buffon
75005 Paris
France
cperrin@mnhn.fr

Chris T. Perry
Department of Environmental & Geographical Sciences
Manchester Metropolitan University
John Dalton Building, Chester Street
Manchester, M1 5GD
UK
c.t.perry@mmu.ac.uk

Michel Pichon
Tropical Marine Consutant
23 Manilla Close
Mount Sheridan Cairns, QLD 4868
Australia
pichon01@bigpond.com

Paolo Antonio Pirazzoli
Centre National de la Recherche Scientifique
16, Rue de la Grange Batelière
75009 Paris
France
paolop@noos.fr

Phillip E. Playford
Geological Survey of Western Australia
100 Plain Street
Perth, WA
Australia
phil.playford@dmp.wa.gov.au

Donald C. Potts
Department of Ecology and Evolutionary Biology
University of California at Santa Cruz
Santa Cruz, CA 95064
USA
potts@biology.ucsc.edu

Samuel Purkis
National Coral Reef Institute
Nova Southeastern University Oceanographic Center
8000 N Ocean Drive
Dania, FL 33004
USA
purkis@nova.edu

Ulrich Radtke
University of Duisburg-Essen
Universitätsstr. 2
45117 Essen
Germany
rektor@uni-due.de

R. Pamela Reid
Rosenstiel School of Marine and Atmospheric Science
University of Miami
4600 Rickenbacker Cswy
Miami, FL 33149
USA
preid@rsmas.miami.edu

Noelle J. Relles
Department of Biological Sciences
Virginia Institute of Marine Science, College of William & Mary
P.O. Box 1346, 1208 Greate Road
Gloucester Point, VA 23062-1346
USA
njrelles@vims.edu

Peter Ridd
Marine Geophysical Laboratory
School of Engineering & Physical Sciences
James Cook University
Townsville, QLD 4811
Australia
peter.ridd@jcu.edu.au

Robert Riding
School of Earth Ocean & Planetary Sciences
Cardiff University
Cardiff, Wales CF10 3YE
UK
and
Department of Earth and Planetary Sciences
University of Tennessee
Knoxville, TN 37996
USA
riding@Cardiff.ac.uk

Bernhard Riegl
National Coral Reef Institute
Oceanographic Center
Nova Southeastern University
8000 N Ocean Drive
Dania, FL 33004
USA
rieglb@nova.edu

Michael J. Risk
Deptartment Of Geology
McMaster University
Hamilton L85 4M1
Canada
and
P.O. Box 1195
Durham, ON
Canada
riskmj@univmail.cis.mcmaster.ca

Harry H. Roberts
Department of Oceanography and Coastal Sciences
Coastal Studies Institute
304 Howe-Russell Geosciences Complex
Louisiana State University
Baton Rouge, LA 70803
USA
hrober3@lsu.edu

J. Fredrick Sarg
Department of Geology & Geological Engineering
Colorado School of Mines
1500 Illinois St
Golden, CO 80401
USA
jsarg@mines.edu

Gerhard Schellmann
Department of Physical Geography & Landscape Studies
University of Bamberg
Am Kranen 1, P.O. Box 1549
96045 Bamberg
Germany
gerhard.schellmann@uni-bamberg.de

Sofia Shah
Department of Chemistry, Faculty of Science and
Technology and Environment
The University of the South Pacific
PMB, Laucala Campus
Suva
Fiji
shahsofia@gmail.com

Yonathan Shaked
Israel National Monitoring Program of the Gulf of Eilat
The Interuniversity Institute for Marine Sciences
POB 469
Eilat, 88103
Israel
shakedyo@cc.huji.ac.il

Charles Sheppard
Department of Biological Sciences
University of Warwick
Coventry, CV4 7AL
UK
charles.sheppard@warwick.ac.uk

Eugene A. Shinn
College of Marine Science
University of South Florida
140 7th Avenue South
St. Petersburg, FL 33701
USA
eshinn@marine.usf.edu

Daria Siciliano
Seaweb Institute of the Environment
Stanford University
8407 Colesville Rd., Suite 500
Silver Spring, MD 20910
USA
daria@biology.ucsc.edu

Scott G. Smithers
School of Earth and Environmental Sciences
James Cook University
Townsville, QLD 4811
Australia
scott.smithers@jcu.edu.au

Thomas Spencer
Cambridge Coastal Research Unit
Department of Geography
University of Cambridge
Downing Place
Cambridge, CB2 3EN
UK
ts111@cam.ac.uk

Lester D. Stephens
Department of History
University of Georgia
1340 Crystal Hills Drive
Athens, GA 30606
USA
lstephen@uga.edu

Thomas Stieglitz
Marine Geophysical Laboratory
James Cook University, School of Engineering & Physical Sciences
Townsville, QLD 4811
Australia
thomas.stieglitz@jcu.edu.au

Andrew C. F. Taylor
Pacificus Biological Services Ltd.
5004, Box 2760
Port Hardy, BC V0N 2P0
Canada
and
James Cook University
Townsville, QLD
Australia
ataylor@pacificus.ca

Frederick W. Taylor
Institute for Geophysics
John A. and Katherine G. Jackson School of Geosciences
University of Texas at Austin
10400 Burnet Rd.
Austin, TX 78758-4445
USA
fred@ig.utexas.edu

Kate J. Thornborough
School of Geosciences
The University of Sydney
Madsen Building (F09) Room 409
Sydney, NSW 2006
Australia
ktho8544@uni.sydney.edu.au

Steve Trudgill
Department of Geography
University of Cambridge, Robinson College
Grange Road
Cambridge, CB3 9AN
UK
steve.trudgill@geog.cam.ac.uk

Maurice Tucker
Department of Earth Sciences
Durham University
Old Elvet
Durham, DH1 3LE
UK
m.e.tucker@durham.ac.uk

Krishnamoorthy Venkataraman
National Biodiversity Authority
475, 9th South Cross Street, Kapaleeswarar Nagar
Neelankarai, Chennai 600 041
India
and
Zoological Survey of India
Marine Biology Regional Centre
130, Santhome High Road
Chennai, 600 028
India
venkyzsi56@yahoo.com

John E. N. Veron
Australian Institute of Marine Science
PMB No 3, MailCentre
Townsville, QLD 4810
Australia
and
Coral Reef Research
10 Benalla Road
Townsville, Oak Valley, QLD 4811
Australia
j.veron@coralreefresearch.com

Carden C. Wallace
Museum of Tropical Queensland
70-102 Flinders St.
Townsville, QLD 4810
Australia
carden.wallace@qm.qld.gov.au

Jody M. Webster
School of Geosciences
The University of Sydney
Sydney, NSW 2006
Australia
jody.webster@sydney.edu.au

Paul Wessel
Department of Geology and Geophysics
School of Ocean and Earth Science and Technology
University of Hawaii at Manoa
1680 East-West Road
Honolulu, HI 96822
USA
pwessel@hawaii.edu

Gareth J. Williams
School of Biological Sciences
Victoria University of Wellington
P.O. Box 600, Wellington
New Zealand
info@garethjwilliams.net

Rachel Wood
School of GeoSciences
Grant Institute, University of Edinburgh
King's Buildings, West Mains Road
Edinburgh, EH9 3JW
UK
Rachel.Wood@ed.ac.uk

Colin D. Woodroffe
School of Earth and Environmental Sciences
University of Wollongong
Wollongong, NSW 2522
Australia
colin@uow.edu.au

Sarah Woodroffe
Department of Geography
Durham University Science Laboratories
South Road
Durham, DH1 3LE
UK
s.a.woodroffe@durham.ac.uk

Philip L. Woodworth
Proudman Oceanographic Laboratory
National Oceanography Centre Liverpool
Joseph Proudman Building, 6 Brownlow Street
Liverpool, L3 5DA
UK
plw@pol.ac.uk

Janie L. Wulff
Department of Biological Science
Florida State University
319 Stadium Drive
Tallahassee, FL 32306-4295
USA
wulff@bio.fsu.edu

Raphael A. J. Wust
School of Earth & Environmental Sciences
James Cook University
Townsville, QLD 4811
Australia
raphael.wust@jcu.edu.au
rwust@cbmsol.com

Yusuke Yokoyama
Atmosphere and Ocean Research Institute
The University of Tokyo
5-1-5 Kashiwanoha
Chiba 277-8564
Japan
yokoyama@aori.u-tokyo.ac.jp

David G. Zawada
U.S. Geological Survey
600 Fourth St. South
St. Petersburg, FL 33701
USA
dzawada@usgs.gov

Jian-xin Zhao
Radiogenic Isotope Laboratory
Centre for Microscopy and Microanalysis
University of Queensland
Brisbane, QLD 4072
Australia
j.zhao@uq.edu.au

Preface

From navigational hazards in the seventeenth and eighteenth centuries to enigmatic scientific features in the nineteenth century, coral reefs over the last 100 years have not only been understood in greater detail but also have provided evidence of macroscale geological processes such as plate tectonics. Charles Darwin's 1842 book based on his 1831–1836 circum global voyage of exploration on HMS *Beagle* strongly focused the interests of science on coral reefs. Interestingly, his ideas of subsiding foundations were developed whilst in South America and before he had seen a coral reef in the field. However, his work promoted both supportive hypotheses and alternatives which included ideas on glacial sea-level control, antecedent platforms, and other ideas which were very much more divorced from field observation than those of Darwin himself, who, in the fourth chapter of his book develops the biological aspects of his theory and the various conditions under which corals can grow.

The ideas, together with his oft quoted wish,

> that some doubly rich millionaire would take into his head to have borings made in some of the Pacific and Indian atolls, and bring home cores for slicing from a depth of 500 or 600 feet

were a forecast of the way coral reef research would travel in the twentieth century. Although many hypotheses have been applied to all scales of reefal features and processes, hypotheses testing is now expected, and with this has come the development of research tools such as survey techniques like aerial photography and satellite imagery. The first views of coral reefs from the sky opened up whole new dimensions and directly aided the field-based study of coral reefs, to the same extent that the laboratory analysis such as palaeoenvironmental reconstruction, has in more recent times.

The understanding of how small polyps can construct enormous coral reefs more than 100 km^2 is of central interest to earth scientists but is just as much the area of many other fields of science. The breakdown of boundaries around the traditional fields of science is a developing theme of the twenty-first century and is no more so than in the study of coral reefs. Corals were initially thought to be plants until the work of André de Peysonnel (1727) although it took another 24 years for the Royal Society of London to accept them as animals. Coral reefs are the largest structures on earth built by a combination of plants and animals and inevitably they have become the major focus of research for zoologists, botanists, and ecologists. It is impossible to study reefs without input of ideas from these disciplines. However, almost every facet of earth science – geology, geography, geomorphology, sedimentology, oceanography, palaeontology, tectonics, etc. – contributes to the understanding of coral reefs and is included in this encyclopedia. The purpose of the encyclopedia is to promote interdisciplinary research and to help in the communication between earth science and other disciplines by providing a window onto the approaches of earth science to coral reefs and giving other disciplines an understanding of the way corals are viewed by the earth science community. As editor of this volume, I see any way that brings the diverse range of disciplines closer together and understanding each other's knowledge as highly productive. However, it is hoped that within the volume there will also be much to help other earth scientists. Every attempt has been made to make the entries as authoritative and up-to-date as possible with latest reference lists and a range of cross-references which will help in the navigation of this volume.

Why the title – *Encyclopedia of Modern Coral Reefs – Structure, Form and Process*? Again, to some extent, it is to make it attractive to multidisciplinary readers. "Cainozoic" or "Quaternary" could have been used but the technical terms may have made it less attractive to other disciplines. Also, modern coral reefs have a continuous lineage with the earliest Palaeozoic reefs, hence the few entries which cover earlier reefs and their influence on today's living reefs in the volume. Structure,

form, and process are the essential ingredients in the earth science recipe for understanding coral reefs as well as most other landforms.

During the last 100 years, coral reefs have attained new values beyond the support of local subsistence economies. They have provided sites for navigational aids and in days of aircraft with limited range, stopover refuelling sites. During World War II many mid-oceanic atolls had strategic importance and following the war, some became testing sites for nuclear weapons. Ironically, the drilling associated with this testing did much to extend the knowledge of the origin of reefs and in particular, support Charles Darwin. Reefs are important sites for commercial as well as subsistence fishing, and further economic value has been added by tourism.

Unfortunately, the future for coral reefs is very uncertain. They are one of the ecosystems most at risk from global climate change and because of this have achieved much prominence in recent times. They have been compared to canaries in coal mines, providing early warning of increasing risks! Both public and scientific perspectives on the impacts of global warming on coral reefs have changed over the last 20 years. Initially a rise in sea level was seen as positive, encouraging new coral growth over largely dead reef flats, although at the other extreme were forecasts of reefs being drowned, all reef islands disappearing and even the reefs themselves being eroded away and tropical coastlines losing their protection. More balanced responses have come as scientists working on processes opened up a range of possibilities. Earth science has played a major role in these revisions especially where cooperation with other disciplines has provided balanced assessments. Impacts will be severe with bleaching from temperature rise and calcification rates declining in response to acidified oceans, leading to unsustainable growth rates of corals and many other important organisms. The earth science focus here is on the impact on sediment budgets and the transportational ability of waves. Many scenarios are possible including an increase in available sediment over the reef top, and, with deeper water greater ability of waves to move both this new sediment and that which may have rested on the reef top for several thousand years, towards any preexisting reef island. At least in the foreseeable future, the actual volume of reef islands may increase, though new areas added will lack vegetation and soils and may be at the expense of the areas which have supported subsistence agriculture for millennia.

What is becoming more apparent, as further research into the impact of climate change on reefs is carried out, is that in many instances there are important thresholds which determine the severity of response. Climate change impact is undoubtedly the most important focus of coral reef research in all disciplines at present. To some extent, the situation is similar to that of the nineteenth century when conflicting hypotheses on the formation of coral reefs were the highlight. Then, as further research revealed the depth and lithology of the foundations, ideas on glacially controlled sea levels became accepted and the whole new scenario of plate tectonics was revealed, it became clear that as in many areas of science, there may be more than one correct answer to a problem. As more thresholds are determined, different options for coral reefs to move into the future will become apparent. Unfortunately, these will mostly be under adverse conditions.

Climate change and coral reefs form one of the major foci of this encyclopedia. Although entries are presented in alphabetical order, they have been organized under major compilation headings which should become particularly obvious when the reader uses the cross-references with each entry. Theories and hypotheses, from Darwin to climate change, also provide a substantial number of entries, together with some of the major methodologies used in the hypothesis testing. Short biographies are given of some of the major contributors to the study of coral reefs in the earth science field, including organizations. Classifications of various features are given, which again show that there may be more than one critical approach to features or processes. Although the encyclopedia does not contain a formal glossary, there are many short entries explaining specific features or processes. As coral reefs vary around the world, a significant number of entries have been devoted to geographical areas. Finally, the past contribution to modern reefs is not forgotten with contributions on specific reef complexes of the geological past, whilst the future, however fragile, is assessed through a number of contributions on conservation.

This is not an exhaustive list but hopefully, it gives a structure to the encyclopedia's contents. Of equal value are the many references given with the entries. These range from some of the most classical to material only published in the last 12 months. The interest in coral reefs is such that, over the next few years, further interesting material will be published and updates may be required, but the 260 entries within the present volume, written by authors from 15 different countries, give a wide perspective of earth science's interest in an increasingly fragile ecosystem.

David Hopley
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This leads to the largest group I wish to acknowledge, the authors of the 260 entries which range in size from a few hundred words up to major contributions of 10,000 words. Many authors have also taken on more than one entry within their speciality area. Also, with authors from 15 different countries for many, English is not their first language, yet, with help from the Editorial Board and from Springer, they have provided quality articles. Inevitably, with such a large group of people there have been problems with illness, with members of their family, etc. and yet, the overall production has not deviated to any great extent from the original timetable. The writers of the articles are highly commended for their dedication to the work.

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