

Ophiolites in Earth History

Geological Society Special Publications

Society Book Editors

R. J. PANKHURST (CHIEF EDITOR)

P. DOYLE

F. J. GREGORY

J. S. GRIFFITHS

A. J. HARTLEY

R. E. HOLDSWORTH

J. A. HOWE

P. T. LEAT

A. C. MORTON

N. S. ROBINS

J. P. TURNER

Special Publication reviewing procedures

The Society makes every effort to ensure that the scientific and production quality of its books matches that of its journals. Since 1997, all book proposals have been refereed by specialist reviewers as well as by the Society's Books Editorial Committee. If the referees identify weaknesses in the proposal, these must be addressed before the proposal is accepted.

Once the book is accepted, the Society has a team of Book Editors (listed above) who ensure that the volume editors follow strict guidelines on refereeing and quality control. We insist that individual papers can only be accepted after satisfactory review by two independent referees. The questions on the review forms are similar to those for *Journal of the Geological Society*. The referees' forms and comments must be available to the Society's Book Editors on request.

Although many of the books result from meetings, the editors are expected to commission papers that were not presented at the meeting to ensure that the book provides a balanced coverage of the subject. Being accepted for presentation at the meeting does not guarantee inclusion in the book.

Geological Society Special Publications are included in the ISI Index of Scientific Book Contents, but they do not have an impact factor, the latter being applicable only to journals.

More information about submitting a proposal and producing a Special Publication can be found on the Society's web site: www.geolsoc.org.uk.

It is recommended that reference to all or part of this book should be made in one of the following ways:

DILEK, Y. & ROBINSON, P. T. (eds) 2003. *Ophiolites in Earth History*. Geological Society, London, Special Publications, **218**.

BAZYLEV, B. A., KARAMATA, S. & ZAKARIADZE, G. S. (2003). Petrology and evolution of the Brezovica ultramafic massif, Serbia. In: DILEK, Y. & ROBINSON, P. T. (eds) *Ophiolites in Earth History*. Geological Society, London, Special Publications, **218**, 91–108.

GEOLOGICAL SOCIETY SPECIAL PUBLICATION NO. 218

Ophiolites in Earth History

EDITED BY

Y. DILEK

Miami University, USA

and

P. T. ROBINSON

Dalhousie University, Canada

2003

Published by
The Geological Society
London

THE GEOLOGICAL SOCIETY

The Geological Society of London (GSL) was founded in 1807. It is the oldest national geological society in the world and the largest in Europe. It was incorporated under Royal Charter in 1825 and is Registered Charity 210161.

The Society is the UK national learned and professional society for geology with a worldwide Fellowship (FGS) of 9000. The Society has the power to confer Chartered status on suitably qualified Fellows, and about 2000 of the Fellowship carry the title (CGeol). Chartered Geologists may also obtain the equivalent European title, European Geologist (EurGeol). One fifth of the Society's fellowship resides outside the UK. To find out more about the Society, log on to www.geolsoc.org.uk.

The Geological Society Publishing House (Bath, UK) produces the Society's international journals and books, and acts as European distributor for selected publications of the American Association of Petroleum Geologists (AAPG), the American Geological Institute (AGI), the Indonesian Petroleum Association (IPA), the Geological Society of America (GSA), the Society for Sedimentary Geology (SEPM) and the Geologists' Association (GA). Joint marketing agreements ensure that GSL Fellows may purchase these societies' publications at a discount. The Society's online bookshop (accessible from www.geolsoc.org.uk) offers secure book purchasing with your credit or debit card.

To find out about joining the Society and benefiting from substantial discounts on publications of GSL and other societies worldwide, consult www.geolsoc.org.uk, or contact the Fellowship Department at: The Geological Society, Burlington House, Piccadilly, London W1J 0BG: Tel. +44 (0)20 7434 9944; Fax +44 (0)20 7439 8975; E-mail: enquiries@geolsoc.org.uk.

For information about the Society's meetings, consult *Events* on www.geolsoc.org.uk. To find out more about the Society's Corporate Affiliates Scheme, write to enquiries@geolsoc.org.uk.

Published by The Geological Society from:
The Geological Society Publishing House
Unit 7, Brassmill Enterprise Centre
Brassmill Lane
Bath BA1 3JN, UK
(Orders: Tel. +44 (0)1225 445046
Fax +44 (0)1225 442836)
Online bookshop: <http://bookshop.geolsoc.org.uk>

The publishers make no representation, express or implied, with regard to the accuracy of the information contained in this book and cannot accept any legal responsibility for any errors or omissions that may be made.

© The Geological Society of London 2003. All rights reserved. No reproduction, copy or transmission of this publication may be made without written permission. No paragraph of this publication may be reproduced, copied or transmitted save with the provisions of the Copyright Licensing Agency, 90 Tottenham Court Road, London W1P 9HE. Users registered with the Copyright Clearance Center, 27 Congress Street, Salem, MA 01970, USA: the item-fee code for this publication is 0305-8719/03/\$15.00.

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library.

ISBN 1-86239-145-9

Typeset by Keytec Typesetting Ltd, Bridport, UK

Printed by Cromwell Press, Trowbridge, UK.

Distributors

USA
AAPG Bookstore
PO Box 979
Tulsa
OK 74101-0979
USA
Orders: Tel. +1 918 584-2555
Fax +1 918 560-2652
E-mail bookstore@aapg.org

India
Affiliated East-West Press PVT Ltd
G-1/16 Ansari Road, Daryaganj,
New Delhi 110 002
India
Orders: Tel. +91 11 2327-9113
Fax +91 11 2326-0538
E-mail affiliat@nda.vsnl.net.in

Japan
Kanda Book Trading Company
Cityhouse Tama 204
Tsurumaki 1-3-10
Tama-shi, Tokyo 206-0034
Japan
Orders: Tel. +81 (0)423 57-7650
Fax +81 (0)423 57-7651
Email geokanda@ma.kcom.nc.jp

Contents

Preface	ix
Introduction	
DILEK, Y. & ROBINSON, P. T. Ophiolites in Earth history: introduction	1
DILEK, Y. Ophiolite pulses, mantle plumes and orogeny	9
Tethyan ophiolites in the Alpine-Himalayan orogenic system	
FLOWER, M. F. J. & DILEK, Y. Arc–trench rollback and forearc accretion: 1. A collision-induced mantle flow model for Tethyan ophiolites	21
DILEK, Y. & FLOWER, M. F. J. Arc–trench rollback and forearc accretion: 2. A model template for ophiolites in Albania, Cyprus, and Oman	43
MÜNTENER, O. & PICCARDO, G. B. Melt migration in ophiolitic peridotites: the message from Alpine–Apennine peridotites and implications for embryonic ocean basins	69
BAZYLEV, B. A., KARAMATA, S. & ZAKARIADZE, G. S. Petrology and evolution of the Brezovica ultramafic massif, Serbia	91
SACCANI, E., PADOA, E. & PHOTIADES, A. Triassic mid-ocean ridge basalts from the Argolis Peninsula (Greece): new constraints for the early oceanization phases of the Neotethyan Pindos basin	109
SARKARINEJAD, K. Structural and microstructural analysis of a palaeo-transform fault zone in the Neyriz ophiolite, Iran	129
AITCHISON, J. C., DAVIS, A. M., ABRAJEVITCH, A. V., ALI, J. R., BADENGZHU, LIU, J., LUO, H., McDERMID, I. R. C. & ZIABREV, S. V. Stratigraphic and sedimentological constraints on the age and tectonic evolution of the Neotethyan ophiolites along the Yarlung Tsangpo suture Zone, Tibet	147
HÉBERT, R., HUOT, F., WANG, C. & LIU, Z. Yarlung Zangbo ophiolites (Southern Tibet) revisited: geodynamic implications from the mineral record	165
MALPAS, J., ZHOU, M.-F., ROBINSON, P. T. & REYNOLDS, P. H. Geochemical and geochronological constraints on the origin and emplacement of the Yarlung Zangbo ophiolites, Southern Tibet	191
Magmatic, metamorphic and tectonic processes in ophiolite genesis	
HARPER, G. D. Tectonic implications of boninite, arc tholeiite, and MORB magma types in the Josephine Ophiolite, California–Oregon	207
SCHROETTER, J. M., PAGÉ, P., BÉDARD, J. H., TREMBLAY, A. & BÉCU, V. Forearc extension and sea-floor spreading in the Thetford Mines Ophiolite Complex	231
RAYMOND, L. A., SWANSON, S. E., LOVE, A. B. & ALLAN, J. F. Cr-spinel compositions, metadunite petrology, and the petrotectonic history of Blue Ridge ophiolites, Southern Appalachian Orogen, USA	253
HIRANO, N., OGAWA, Y., SAITO, K., YOSHIDA, T., SATO, H. & TANIGUCHI, H. Multi-stage evolution of the Tertiary Mineoka ophiolite, Japan: new geochemical and age constraints	279
TAKAHASHI, A., OGAWA, Y., OHTA, Y. & HIRANO, N. The nature of faulting and deformation in the Mineoka ophiolite, NW Pacific Rim	299

STAKES, D. S. & TAYLOR, H. P. Jr Oxygen isotope and chemical studies on the origin of large plagiogranite bodies in northern Oman, and their relationship to the overlying massive sulphide deposits	315
Hydrothermal and biogenic alteration of oceanic crust as recorded in ophiolites	
GREGORY, R. T. Ophiolites and global geochemical cycles: implications for the isotopic evolution of seawater	353
GIGUÈRE, E., HÉBERT, R., BEAUDOIN, G., BÉDARD, J. H. & BERCLAZ, A. Hydrothermal circulation and metamorphism in crustal gabbroic rocks of the Bay of Islands ophiolite complex, Newfoundland, Canada: evidence from mineral and oxygen isotope geochemistry	369
MUEHLENBACHS, K., FURNES, H., FONNELAND, H. C. & HELLEVANG, B. Ophiolites as faithful records of the oxygen isotope ratio of ancient seawater: the Solund–Stavfjord Ophiolite Complex as a Late Ordovician example	401
FURNES, H. & MUEHLENBACHS, K. Bioalteration recorded in ophiolitic pillow lavas	415
Ophiolite emplacement: mechanisms and processes	
WAKABAYASHI, J. & DILEK, Y. What constitutes ‘emplacement’ of an ophiolite?: Mechanisms and relationship to subduction initiation and formation of metamorphic soles	427
GRAY, D. R. & GREGORY R. T. Ophiolite obduction and the Samail Ophiolite: the behaviour of the underlying margin	449
SEARLE, M. P., WARREN, C. J., WATERS, D. J. & PARRISH, R. R. Subduction zone polarity in the Oman Mountains: implications for ophiolite emplacement	467
Regional occurrence of ophiolites and geodynamics	
HARRIS, R. Geodynamic patterns of ophiolites and marginal basins in the Indonesian and New Guinea regions	481
MILSOM, J. Forearc ophiolites: a view from the western Pacific	507
SPAGGIARI, C. V., GRAY, D. R. & FOSTER, D. A. Tethyan- and Cordilleran-type ophiolites of eastern Australia: implications for the evolution of the Tasmanides	517
ZHANG, Q., WANG, Y., ZHOU, G. Q., QIAN, Q. & ROBINSON P. T. Ophiolites in China: their distribution, ages and tectonic settings	541
SPADEA, P., ZANETTI, A. & VANNUCCI, R. Mineral chemistry of ultramafic massifs in the Southern Uralides orogenic belt (Russia) and the petrogenesis of the Lower Palaeozoic ophiolites of the Uralian Ocean	567
ISHIWATARI, A., SOKOLOV, S. D. & VYSOTSKIY S. V. Petrological diversity and origin of ophiolites in Japan and Far East Russia with emphasis on depleted harzburgite	597
SOKOLOV, S. D., LUCHITSKAYA, M. V., SILANTYEV, S. A., MOROZOV, O. L., GANELIN, A. V., BAZYLEV, B. A., OSIPENKO, A. B., PALANDZHIAN, S. A. & KRAVCHENKO-BEREZHNOY, I. R. Ophiolites in accretionary complexes along the Early Cretaceous margin of NE Asia: age, composition, and geodynamic diversity	619
STERN, C. R. & DE WIT, M. J. Rocas Verdes ophiolites, southernmost South America: remnants of progressive stages of development of oceanic-type crust in a continental margin back-arc basin	665
DILEK, Y. & AHMED, Z. Proterozoic ophiolites of the Arabian Shield and their significance in Precambrian tectonics	685

Preface

This book is derived from the interdisciplinary, contemporary work of the international ophiolite community in a most up-to-date treatment of process-oriented problems and questions on the generation and evolution of ophiolites. It is a large collection of research papers from a wide range of international contributors. Some of these papers were presented in thematic ophiolite sessions at the 2001 Annual Meeting of the Geological Society of America (Boston) and the 2001 Fall Meeting of the American Geophysical Union (San Francisco). The 32 papers here examine the mode and nature of igneous, metamorphic, tectonic, sedimentological, and biological processes associated with the evolution of oceanic crust in different tectonic settings in Earth history as revealed in various ophiolites and ophiolite belts around the world, and the geodynamic significance of these ophiolites in the evolution of different orogenic systems. Divided into six thematic sections, the book presents a wealth of new data and syntheses from mainly Phanerozoic ophiolites around the world.

We would like to express our thanks to the contributors to this book for their time and effort. We also would like to extend our sincere appreciation and gratitude to Angharad Hills (Staff Editor) and Andy Morton (Book Series Editor) for their help and advice at review stages, and to the Geological Society Publishing House staff for their support in the publication process. Diligent work by Senior Production Editor Sarah Gibbs at all stages throughout the preparation and reproduction of this book contributed to its success. Cathy Edwards in the Geology Department at Miami University helped with manuscript preparation and proofreading of the chapters. The Office of Advancement of Research and Scholarship, the College of Arts and Science, and the Department of Geology at Miami University provided partial financial support for the preparation of the book that we gratefully acknowledge.

We wish to thank the following colleagues for their timely and thorough reviews of the manuscripts that helped us maintain the high scientific standards for which we have striven:

James Allan (Appalachian State University, USA); Jeffrey C. Alt (University of Michigan, USA); Shoji Arai (Kanazawa University, Japan); Neil Banerjee (University of Alberta, Canada); Asish Basu (University of Rochester, New York, USA); Jean Bébien (Université de Paris-Sud, Orsay, France); Manuel Berberian (New Jersey, USA); Sherman Bloomer (Oregon State University, USA); Craig Buchan (Curtin University of Technology, Australia); Sun-Lin Chung (National Taiwan University, Taiwan); Ian W.D. Dalziel (University of Texas at Austin, USA); Hugh Davies (University of Papua New Guinea);

Yildirim Dilek (Miami University, USA); Jaroslav Dostal (St. Mary's University, Canada); Grenville Draper (Florida International University, USA); Stephen Edwards (University of Greenwich, England); Don Elthon (University of Houston, USA); John Encarnacion (St. Louis University, USA); Martin Fisk (Oregon State University, USA); Martin F.J. Flower (University of Illinois at Chicago, USA); Gretchen Frueh-Green (ETH-Zentrum, Switzerland); Ulrich Glasmacher (Germany); David Gray (University of Melbourne, Australia); Ron Harris (Brigham Young University, USA); Kendall Hauer (Miami University, USA); James W. Hawkins (Scripps Institution of Oceanography, California, USA); Réjean Hébert (Université Laval, Québec, Canada); Rod Holcombe (University of Queensland, Australia); Paul Holm (Earlham College, USA); Francois Huot (Université Laval, Québec, Canada); Akira Ishiwatari (Kanazawa University, Japan); Barbara John (University of Wyoming, USA); Thierry Juteau (IUEM, Plouzane, France); Ade Kadarusman (Tokyo Institute of Technology, Japan); Andrew Kerr (Cardiff University, UK); Elena Konstantinovskaia (Russian Academy of Sciences, Moscow-Russia); John Malpas (University of Hong Kong, China); Catherine Mével (Institute de Physique du Globe, Paris-France); Calvin Miller (Vanderbilt University, USA); John Milsom (University College London, UK); Eldridge Moores (University of California at Davis, USA); Kula Misra (University of Tennessee, USA); Karlis Muehlenbachs (University of Alberta, Canada); Christopher Parkinson (University of New Orleans, USA); Gene Perry (Northern Illinois University, USA); Tjerk Peters (Universität Bern, Switzerland); Ali Polat (University of Windsor, Canada); Elisabetta Rampone (University of Genova, Italy); Paul T. Robinson (Dalhousie University, Canada); Andrew Saunders (University of Leicester, UK); Peter Schiffman (University of California at Davis, USA); Richard Sedlock (San Jose State University, California, USA); John Shervais (Utah State University, USA); Eli Silver (University of California at Santa Cruz, USA); Ian Smith (The University of Auckland, New Zealand); Piera Spadea (Università di Udine, Italy); Catherine Spaggiari (Monash University, Australia); Debra Stakes (MBARI, California, USA); Hubert Staudigel (Scripps Institution of Oceanography, California, USA); Charles Stern (University of Colorado, USA); Mohamed Sultan (University at Buffalo, New York, USA); Damon A. H. Teagle (University of Southampton, UK); David Vanko (Towson University, Maryland); John Wakabayashi (Hayward, USA); and Steve Wojtal (Oberlin College, USA).

Yildirim Dilek
Oxford, USA, October 2003