

Deformation Mechanisms, Rheology and Tectonics:
Current Status and Future Perspectives

Geological Society Special Publications

Society Book Editors

A. J. FLEET (CHIEF EDITOR)

P. DOYLE

F. J. GREGORY

J. S. GRIFFITHS

A. J. HARTLEY

R. E. HOLDSWORTH

A. C. MORTON

N. S. ROBINS

M. S. STOKER

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:

DE MEER, S., DRURY, M. R., DE BRESSER, J. H. P. & PENNOCK, G. M. (eds) 2002. *Deformation Mechanisms, Rheology and Tectonics: Current Status and Future Perspectives*. Geological Society, London, Special Publications, 200.

ZHU, W., MONTÉSI, L. G. J. & WONG, T.-F. 2002. Effects of stress on the anisotropic development of permeability during mechanical compactions of porous sandstones. *In*: DE MEER, S., DRURY, M. R., DE BRESSER, J. H. P. & PENNOCK, G. M. (eds) *Deformation Mechanisms, Rheology and Tectonics: Current Status and Future Perspectives*. Geological Society, London, Special Publications, 200, 119–136.

GEOLOGICAL SOCIETY SPECIAL PUBLICATION NO. 200

**Deformation Mechanisms, Rheology and Tectonics:
Current Status and Future Perspectives**

EDITED BY

**S. DE MEER, M. R. DRURY, J. H. P. DE BRESSER
& G. M. PENNOCK**

Utrecht University, The Netherlands

2002

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 2001. 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 0305-8719/02/\$15.00.

British Library Cataloguing in Publication Data

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

ISBN 1-86239-117-3

Typeset by Wyvern 21 Ltd
Printed by Cambrian Printers Ltd, Aberystwyth

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 11 327-9113
Fax +91 11 326-0538
E-mail affiliat@nda.vsnl.net.in

Japan

Kanda Book Trading Co.
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

Contents

Preface	vii
DE MEER, S., DRURY, M. R., DE BRESSER, J. H. P. & PENNOCK, G. M. Current issues and new developments in deformation mechanisms, rheology and tectonics	1
The effect of fluids on deformations	
ZHANG, X., SALEMANS, J., PEACH, C. J. & SPIERS, C. J. Compaction experiments on wet calcite powder at room temperature: evidence for operation of intergranular pressure solution	29
GUNDERSEN, E., DYSTHE, D. K., RENARD, F., BJØRLYKKE, K. & JAMTVEIT, B. Numerical modelling of pressure solution in sandstone, rate limiting processes and the effect of clays	41
NIEMEIJER, A. R. & SPIERS, C. J. Compaction creep of quartz-muscovite mixtures at 500 °C: Preliminary results on the influence of muscovite on pressure solution	61
DEN BROK, B., MOREL, J. & ZAHID, M. <i>In situ</i> experimental study of roughness development at a stressed solid/fluid interface	73
LE HÉBEL, F., GAPAIS, D., FOURCADE, S. & CAPDEVILA, R. Fluid-assisted large strains in a crustal-scale décollement (Hercynian Belt of South Brittany, France)	85
ELBURG, M. A., BONNS, P. D., FODEN, J. & PASSCHIER, C. W. The origin of fibrous veins: constraints from geochemistry	103
ZHU, W., MONTÉSI, L. G. J. & WONG, T.-F. Effects of stress on the anisotropic development of permeability during mechanical compaction of porous sandstones	119
The interpretation of microstructures and textures	
JESSELL, M. W. & BONNS, P. D. The numerical simulation of microstructure	137
PIAZOLO, S., BONNS, P. D., JESSELL, M. W., EVANS, L. & PASSCHIER, C. W. Dominance of microstructural processes and their effect on microstructural development: insights from numerical modelling of dynamic recrystallization	149
STIPP, M., STÜNITZ, HEILBRONNER, R. & SCHMID, S. M. Dynamic recrystallization of quartz: correlation between natural and experimental conditions	171
HEILBRONNER, R. & TULLIS, J. The Effect of Static Annealing on microstructures and crystallographic preferred orientations of quartzites experimentally deformed in axial compression and shear	191
LEISS, B., GRÖGER, H. R., ULLEMEYER, K. & LEBIT, H. Textures and microstructures of naturally deformed amphibolites from the northern Cascades, NW USA: methodology and regional aspects	219
ZUCALI, M., CHATEIGNER, D., DUGNANI, M., LUTTEROTTI, L. & OULADDIAF, B. Quantitative texture analysis of glaucophanite deformed under eclogite facies conditions (Sesia-Lanzo Zone, Western Alps): comparison between X-ray and neutron diffraction analysis	239
Deformation mechanisms and rheology of crust and upper mantle minerals	
STÖCKHERT, B. Stress and deformation in subduction zones - insight from the record of exhumed metamorphic rocks	255
BURG, J.-P. & VIGNERESSE, J.-L. Non-linear feedback loops in the rheology of cooling-crystallising felsic magma and heating-melting felsic rock	275
RENNER, J. & EVANS, B. Do calcite rocks obey the power-law creep equation?	293
DE BRESSER, J. H. P., EVANS, B. & RENNER, J. On estimating the strength of calcite rocks under natural conditions	309

TER HEEGE, J. H., DE BRESSER, J. H. P. & SPIERS, C. J. The influence of dynamic recrystallization on the grain size distribution and rheological behaviour of Carrara marble deformed in axial compression	331
Crust and lithosphere tectonics	
BRUN, J.-P. Deformation of the continental lithosphere: insights from brittle-ductile models	355
WIESMAYR, G., EDWARDS, M. A., MEYER, M., KIDD, W. S. F., LEBER, D., HÄUSLER, H. & WANGDA, D. Evidence for steady fault-accommodated strain in the High Himalaya: progressive fault rotation of the southern Tibet detachment system in NW Bhutan	371
HANDY, M. R. & STÜNITZ, H. Strain localization by fracturing and reaction weakening – A mechanism for initiating exhumation of subcontinental mantle beneath rifted margins	387
Index	409

Preface

This special volume is a collection of original papers and review articles based on work presented at the Deformation mechanisms, Rheology and Tectonics (DRT2001) conference, which was held in Noordwijkerhout, Netherlands in April 2001. DRT2001 was the twelfth in a series of international conferences that began in 1976 with a meeting organised by Henk Zwart, Richard Lisle, Gordon Lister and Paul Williams from the Geologisch en Mineralogisch Instituut der Rijksuniversiteit, Leiden. Special publications arising from these meetings are listed below. The Leiden meeting on Fabrics, Microtextures and Microtectonics 'was designed to bring together as many as possible of the people active in this field; not only geologists but also material scientists from other disciplines' (Lister *et al.* 1977). The topics considered in the conferences have evolved and changed but have always remained within the broad field of deformation processes. In 1999 a permanent name was adopted for the conference series, namely, 'Deformation mechanisms, Rheology and Tectonics' (Dresen & Handy 2001). The DRT meetings are devoted to the study of deformation behaviour and the rheology of rocks and minerals and to encourage dialogue between researchers working on all scales of field, experimental and theoretical studies of rock deformation. Recent DRT meetings have aimed to provide a forum where field geologists could get state-of-the-art information on experimental and theoretical studies and where theoreticians and experimentalists could debate the problems and questions posed by natural structures and microstructures (Schmid *et al.* 1999). The main focus of DRT2001 in Noordwijkerhout was on the progress made in the 25 years since the original Leiden meeting and the direction that our research should take in the new millennium. Professor Henk Zwart and Professor Paul Williams were special guests at the meeting. DRT2001 was organized by an informal group from the Faculty of Earth Sciences, Utrecht University including Siese de Meer, Martyn Drury, Magda Martens, Pat Trimby, Gill Pennock, Saskia ten Grotenhuis, and Jaap Liezenberg with support from Professor Chris Spiers and Professor Stan White.

We thank the sponsors of DRT2001 for financial support towards the conference and this special publication. We would also like to especially thank the referees for their important contribution: P. Bate, C. Beaumont, T. Blenkinsop, B. Bos, B. den Brok, P. Chopra, S. Covey-Crump, G. Dresen, M. Drury, B. Evans, D. Gapais, J. Ghoussoub, J.-P. Gratier, H. Green II, F. Gueydan, M. Handy, F. Heidelbach, R. Heilbronner, R. Holdsworth, K. Kanagawa, R. Kerrick, J. Kruhl, K. Kunze, B. Leiss, G. Lloyd, R. Lisle, I. Main, P. Mason, A. McGaig, J. Newman, D. Nieuwland, Y.-D. Park, C. Peach, J. Raphanel, F. Renard, E. Rutter, C. Simpson, K. Schulmann, W. Skrotski, C. Spiers, P. Trimby, J. Urai, J. White, C. Wilson and six anonymous reviewers.

Martyn Drury, Siese de Meer, Hans de Bresser and Gill Pennock
Utrecht March 2002.

DRT conference volumes

- Leiden, Netherlands 1976. LISTER, G.S., WILLIAMS, P.F., ZWART, H.J. & LISLE, R.J. (eds) 1977. Fabrics, microstructures and microtectonics. *Tectonophysics*, **39**, 1–487.
- Göttingen, W. Germany, 1981. LISTER G.S., BEHR, H.-J., WEBER, K. & ZWART, H.J. (eds) 1981. The effect of deformation on rocks. *Tectonophysics*, **78**, 1–698.
- Zürich, Switzerland, 1982. HANCOCK, P.L., KLAPER, E.M., MANCKTELOW, N.S. & RAMSAY, J.G. (eds) 1984. Planar and linear fabrics of deformed rocks. *Journal of Structural Geology*, **6**, 1–287.
- Utrecht, Netherlands, 1985. ZWART, H.J. MARTENS, M., VAN DER MOLEN, I., PASSCHIER, C.W., SPIERS, C.J., & VISSERS, R.L.M. (eds) 1987. Tectonic and structural processes on a Macro-meso- and micro-scale. *Tectonophysics*, **135**, 1–251.
- Uppsala, Sweden, 1987. TALBOT, C. (ed.) 1988. *Geological Kinematics and Dynamics: special volume in honour of the 70th birthday of Hans Ramberg*. Acta Universitatis Upsaliensis, Bulletin of the Geological Institutions of the University of Uppsala, New Series, **14**.
- Leeds, Gt. Britain, 1989. KNIPE, R.J. & RUTTER, E.H. (eds) 1990. *Deformation Mechanisms, Rheology and Tectonics*. Geological Society, London, Special Publications, **54**.
- Montpellier, France, 1991. BURG J-P, MAINPRICE, D. & PETIT, J.P. (eds) 1992. Special Issue-Mechanical instabilities in rocks and tectonics. *Journal of Structural Geology*, **14**, 893–1109.
- Graz, Austria, 1993. WALLBRECHER, E., UNZOG, W. & BRANDMAYR, M. (eds) 1994. Structures and tectonics at different lithospheric levels – a selection of papers presented at the International conference on structures and tectonics at different lithospheric levels, Graz, Austria. *Journal of Structural Geology*, **16**, 1495–1575.
- Prague, Czechoslovakia 1995. SCHULMANN, K. (ed.) 1997. Thermal and mechanical interactions in deep-seated rocks. *Tectonophysics*, **280**, 1–197.
- Basel, Switzerland, 1997. SCHMID, S.M., HEILBRONNER, R. & STÜNITZ, H. (eds) 1999. Deformation mechanisms in nature and experiment. *Tectonophysics*, **303**, 1–319.
- Neustadt an der Weinstrasse, Germany, 1999. DRESEN, G. & HANDY, M. (eds) 2001. International conference on ‘Deformation mechanisms, rheology and microstructures’ Neustadt an der Weinstrasse, 22–26 March 1999. *International Journal of Earth Sciences (Geologische Rundschau)* **90**, 1–210.

List of Sponsors

- KNAW: Royal Netherlands Academy of Arts and Sciences.
- ISIS: Netherlands Research Centre for Integrated Solid Earth Sciences.
- VMSG: Vening Meinesz Research School of Geodynamics.
- GOI: Geodynamics Research Institute, Faculty of Earth Sciences, Utrecht University.
- Stichting Electronen Microscopie Netherlands.
- Nederlandse Aardolie Maatschappij bv., Netherlands.
- Akzo Nobel Chemicals bv, Netherlands
- Electronen Optik Service GmbH, Germany.
- HKL Technology ApS, Denmark.
- Corus, Netherlands.
- NITG: Netherlands Institute for Applied Geosciences.
- TSL/EDX, Netherlands.
- FEI/ Philips Electron Optics, Netherlands.