Crustal Heat Flow

A Guide to Measurement and Modelling

Crustal Heat Flow: A Guide to Measurement and Modelling is a handbook for geologists and geophysicists who manipulate thermal data, particularly for petroleum exploration.

Heat flow data can provide an indication of past geological events and present economic potential of fossil fuel deposits. In theory and with practical examples the first two parts of the book discuss the sources of heat within the crust, describe how to maximise the accuracy of temperature data, cover the measurement of the thermal properties of rocks, and explain a number of maturity indicators. The last part of the book covers a range of thermodynamic models of the lithosphere and goes on to show how these can be used to reconstruct the thermal history of individual sedimentary basins. The focus remains consistently on practical applications, with worked examples providing a comprehensive guide for data reduction and interpretation.

This text will be attractive to a broad range of earth scientists. Many geologists will be interested in applications for global modelling and structural geology, but the topics covered will also be of specific interest to the oil exploration industry. This book will be regarded as a long-term reference source for professionals and researchers. It will also form the basis of advanced undergraduate and graduate student courses in geology, geophysics, engineering, mining, and environmental science, and will be a valuable text for petroleum industry training schemes.

G. R. Beardsmore is a Research Fellow at the Department of Earth Sciences, Monash University, Australia. Dr Beardsmore received his PhD from Monash in 1996. During his time as a student he was the principal researcher and coordinator of an industry-sponsored programme, *'Heat Flow Compilations and Thermal Maturation for Petroleum Exploration in NW Australia'*. After completing his PhD he spent time working with heat flow researchers in China (Changsha Institute of Geotectonics) and the United States (Southern Methodist University). He has published around a dozen papers on heat flow and tectonic evolution and has contributed to chapters in the volumes *'Applications of Emerging Technologies: Unconventional Methods in Exploration for Petroleum and Natural Gas'* (1997; ISEM, SMU, Dallas TX) and *'Geothermics in Basin Analysis'* (1999; Kluwer Academic/Plenum Publishers). Dr Beardsmore is a Member of the Petroleum Exploration Association of Australia (PESA), the American Geophysical Union (AGU) and the American Association of Petroleum Geologists (AAPG).

J. P. Cull is a Professor of Geophysics at the Department of Earth Sciences, Monash University, Australia. After joining the Australian Bureau of Mineral Resources he received an Australian Public Service scholarship leading to the award of a PhD from Oxford University in 1973–75. He was subsequently awarded a French Government Fellowship for Science and Technology concentrating on geothermal studies at BRGM (Orleans). After returning to Australia he was employed by CRA Exploration Pty Ltd as Principal Geophysicist responsible for the application of electrical and EM methods for base metal exploration. He joined the staff of Monash University in 1986 and was responsible for introducing a full range of geophysical coursework options. Professor Cull continues to conduct research in heat flow, geodynamics, electromagnetics, mineral exploration, and geotechnical studies. He is a Fellow of the Australian Institute of Mining and Metallurgy (F.AusIMM), a Fellow of the Australian Institute of Energy (F.AIE), a Member of the Australian Society of Exploration Geophysics (ASEG) and a Member of the Environmental and Engineering Geophysics Society (EEGS).

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CAMBRIDGE
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK http://www.cup.cam.ac.uk
40 West 20th Street, New York, NY 10011–4211, USA http://www.cup.org
10 Stamford Road, Oakleigh, Melbourne 3166, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain

First published 2001

Printed in the United States of America

Typeface Times 10.75/13pt

*A catalog record for this book is available from
the British Library*

Library of Congress Cataloging-in-Publication Data

Beardsmore, G. R. (Graeme Ross)
Crustal heat flow: a guide to measurement and modelling / G. R. Beardsmore, J. P. Cull.
p. cm.
Includes bibliographical references and index.
ISBN 0-521-79289-4 – ISBN 0-521-79703-9 (pb)
1. Terrestrial heat flow – Measurement. 2. Earth – Crust. I. Cull, J. P. (James Phillip) II. Title.

QE509.8.B43 2001
551.1′4 – dc21 00-048634

ISBN 0 521 79289 4 hardback
ISBN 0 521 79703 9 paperback

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Preface

> The first step is to make sure of the facts themselves. In other words – What is the law regulating this increase of heat? At what rate does the temperature augment? This might be supposed to be a point easily settled. It might be supposed that nothing would be easier than to insert thermometers into the rock at different depths in a mine, and to read off their indications; or to lower them into a borehole for the same purpose. But there are many difficulties to be overcome, and a host of disturbing causes present.
>
> *Physics of the Earth's Crust* – Rev. Osmond Fisher, 1881, p. 4.

Heat flow data have been used extensively by geoscientists to provide an indication of temperature variations within the Earth. However, there are relatively few experts available with the necessary experience to provide a critique of the central constraints or to obtain new data for second-order models. Terminology relating to thermal conductivity, diffusivity, vitrinite reflectance, xenolith geochemistry, and so on, is widely recognised but poorly understood, particularly by industry professionals.

As an example, the present state of geothermal modelling and interpretation in the petroleum industry is a peculiar one. On the one hand, there are numerous highly sophisticated software applications on the market for solving the complex equations governing the thermal evolution of sedimentary basins and the maturation of organic material. On the other hand, however, the accurate use of these packages requires considerable knowledge of the underlying physical concepts and a wealth of reliable data. Both commodities are in short supply and complex interpretations are often based on an inadequate appreciation of the primary constraints. Consequently, this book grew from a desire to address the problem of education, by covering the fundamental concepts of heat flow from both a practical and a theoretical point of view.

When we first began work on this book, our objectives were relatively simple, with few concerns regarding the scope and range of topics it would eventually cover. The text began its life as a short monograph covering some fundamental aspects of heat flow measurements and geothermal modelling, but the more we progressed into it, the more we discovered the truth of the good Reverend Fisher's words from 1881. The book ended up as a text covering

almost every aspect of thermal modelling in at least a basic way. From discussions with practising petroleum geologists we were able to pinpoint some of the 'many difficulties' and 'disturbing causes' and address them directly by way of explanation and example.

In this day and age, print media can be somewhat limited in its abilities to present available information. For this reason, a web site has been set up at

http://www.earth.monash.edu.au/heatflow/

as an ongoing source of support in addition to the information and concepts described and explained in the text. The web site includes colour versions of many of the figures, links to useful web sites elsewhere in the world, an up-to-date list of relevant publications, and small software applications that implement some of the concepts discussed in the book. It is hoped that this book and the associated web site will become useful companions for the general geophysical community, and more specifically the petroleum geologist, struggling to make sense of the sophisticated software tools at his or her disposal.

It is necessary now to acknowledge and thank some of the many people who have directly or indirectly helped in the production of this manuscript. In a way, Barry Goldstein is the godfather of the work, without whom G.R.B. would not have been lured into the field of geothermal research at all. Trevor Graham and Mike Swift, of the then Bureau of Mineral Resources in Canberra, were instrumental in providing G.R.B. with his first geothermal field experience in the active volcanic cauldera of Rabaul Harbor, Papua New Guinea. Such exotic locations are one of the great rewards of this field of work. Deeper in the past, J.P.C. was privileged to enjoy the fundamental supervision of Ron Oxburgh and Steve Richardson at Oxford. They greatly assisted in developing a range of heat flow methods still in current use.

More direct involvement in the manuscript preparation came by way of discussion of content and critical feedback from Neil Sherwood, Gareth Cooper, Frank Maio, Iain Bartholomew, Jason McKenna and particularly David Blackwell. Others who have in some way contributed, through casual discussions, responses to requests for information, or various other means, include Malcolm Altmann, George Asquith, Will Gosnold, Greg Houseman, Mark Lisk, Arthur Mory, Bob Nicoll, Paul O'Sullivan, Walter Pickel, Nigel Russell, Sun Shaohua, Alister Terry and Yoshihiro Ujiié. Our editor, Matt Lloyd, was particularly prompt and helpful whenever we had need of his assistance.

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