Mike Leeder

Second Edition

Sedimentology and Sedimentary Basins

From Turbulence to Tectonics

WILEY-BLACKWELL

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Sedimentology and Sedimentary Basins

From Turbulence to Tectonics

2nd Edition

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WILEY-BLACKWELL
A John Wiley & Sons, Ltd., Publication

Blackwell Publishing was acquired by John Wiley & Sons in February 2007. Blackwell's publishing program has been merged with Wiley's global Scientific, Technical and Medical business to form Wiley-Blackwell.

Registered office: John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial offices: 9600 Garsington Road, Oxford, OX4 2DQ, UK
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK
111 River Street, Hoboken, NJ 07030-5774, USA

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Library of Congress Cataloguing-in-Publication Data

Leeder, M. R. (Mike R.)
Sedimentology and sedimentary basins : from turbulence to tectonics / Mike Leeder.–2nd ed.
p. cm.
Includes index.
Summary: “The sedimentary record on Earth stretches back more than 4.3 billion years and is present in more abbreviated forms on companion planets of the Solar System, like Mars and Venus, and doubtless elsewhere. Reading such planetary archives correctly requires intimate knowledge of modern sedimentary processes acting within the framework provided by tectonics, climate and sea or lake level variations. The subject of sedimentology thus encompasses the origins, transport and deposition of mineral sediment on planetary surfaces. The author addresses the principles of the subject from the viewpoint of modern processes, emphasising a general science narrative approach in the main text, with quantitative background derived in enabling ‘cookie’ appendices. The book ends with an innovative chapter dealing with how sedimentology is currently informing a variety of cognate disciplines, from the timing and extent tectonic uplift to variations in palaeoclimate. Each chapter concludes with a detailed guide to key further reading leading to a large bibliography of over 2500 entries. The book is designed to reach an audience of senior undergraduate and graduate students and interested

academic and industry professionals."– Provided by publisher.

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1. Sedimentology. 2. Sedimentary basins. I. Title.
QE471.L375 2010
552′.5-dc22
2010023320
ISBN 978-1-4443-4992-4 (hbk)—978-1-4051-7783-2 (pbk.)

Preface

World is crazier and more of it than we think, Incorrigibly plural.

Louis MacNeice, ‘Snow’, Collected Poems, Faber

The predecessors to this book, *Sedimentology: Process and Product* (Allen and Unwin, 1982) and *Sedimentology and Sedimentary Basins: from Turbulence to Tectonics* (Blackwell Science 1999) are out of print and partly outdated respectively. I have received much feedback from many persons who have used these books over the years and the current version is intendedto trytorecapture the spiritofadynamic and widely applied science. Reasons of space have pre-ventedme from dealing with the subjects of diagenesis and the transformation of sediment to sedimentary rock. I have replaced these with chapters linking sedimentology to climate, sea-level change, tectonics, sedimentary basin architecture and their role in solving interdisciplinary problems. I feel somewhat uneasy about the omission, but it strikes me that the subject of diagenesis has become so based upon the physics of subsurface water flow and the chemistry of low temperature water–rock interactions that the difference of emphasis is too much to encompass within the present text.

Progress over the past decade has been breathtaking. Take some examples: the flow dynamics of opaque mud suspensions can now be monitered by acoustic Doppler probes; knowledge of deep-sea environments has been revolutionized by improved sea-bed imaging; sedimentological reactions to climatic and sea-level change have proved robust and sedimentology contributes vitally to the understanding of the evolution of sedimentary basins, from the birth, life and death of bounding faults to the climatic and palaeontological record contained within them. Further, carbonate sediments and their contained O_2 stable isotopes play a key role in establishing ancient oceanic composition (evaporite fluid inclusions), the palaeoaltimetry of high mountains and plateau (calcisols) and the determination of ancient climate (speleothem). All this means that sedimentology is not something that can be done in isolation; the holistic approach is that which I have taken in this book, one based on a thorough understanding of modern processes that I trust will propel the reader into an enthusiasm for the subject and a sense of its place in the wider scheme of earth sciences, specifically in attempts to read the magnificent rock record.

Who do I expect to be reading this book? You will have completed an introductory course in general geology, earth or environmental sciences, and perhaps a more specific basic one in sedimentology or sedimentary geology. You will thus know the basic sediment and sedimentary rock types and also know something of the place of the subject within the broader earth and environmental sciences. You will have enough basic science background to understand, if not feel exactly on top of, Newton’s laws, basic thermodynamics and aqueous chemistry. Though mathematically challenged, like many earth scientists including myself, you should at least know where to find out how to manipulate equations to a reducible form. I make no apology for spending a little more time with basic fluid dynamics than with the thermodynamics. This is not because I find one more interesting or important than the other—it’s just that most high school leavers and graduating university students (even those of physics) do little in the way of fluid mechanics in their syllabi nowadays and it seemed that the theme of ‘sedimentological fluid dynamics’ is just such a place to set up some sort of foundation. Philosophically you should want to reduce the complicated natural world to an orderly scheme, but at the same time not want to miss out on the romance and poetry of an unclassifiable subject. You will be someone who enjoys talking and arguing with a variety of other earth science specialists.

Just a few final notes are in order.

- More involved derivations of essential physical and chemical concepts are to be found in the end section labelled 'Cookies'. These are meant to be helpful for intellectual health. There is also a short mathematical refresher appendix. I would appreciate it if readers let me know of any mistakes or symbol typos I may have made as I hope to live long enough to make another edition, someday.
- I have tried my best to reference major developments correctly at the end of chapters, to make sure the source of specific case histories can be traced and to respect historical precedence and discoveries. References are given in abbreviated form, but quite sufficient to be of full use in rapid web-based search vehicles like *Web of Science*.
- Many graphs with data points have been generalized to 'clouds' or 'envelopes' of data points—if you wish toget the original data,gobacktothe citedreferences.

Thanks to colleagues and friends who either directly, through conversation, or indirectly through me reading their works, have inspired my continued interest in sedimentology and its many applications. I would like in particular to thank long-time collaborators and friends Jan Alexander, Julian Andrews, Jim Best, John Bridge, Rob Gawthorpe and Greg Mack for keeping my mind stretched over past years. I also extend my heartfelt thanks to former faculty colleagues at the fine Universities of Leeds and East Anglia where I have spent my professional life, together with my ex-undergraduate and graduate students, for keep-ingmeonmytoes.IamgratefultoDrJenny Mason for writing the sections on terrestrial carbonates (section 2.9), the role of speleothems in palaeoclimatic studies (section 23.18) and, with Dr James Hodson, for compiling the reference list. Finally, thanks to the whole production team at Wiley-Blackwell and to Ian Francis for his gentlemanly encouragement to complete this project and for putting up with some delays over the past 4 years as I periodically got on with my research and real life instead!

Mike Leeder

Brooke, Norwich

January, 2010

Acknowledgements

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7, 6.18, 7.2, 7.7, 7.12–13, 7.22–23, 7.26, 7.31, 7.39, 7.43, 7.45, 7.47–49, 8.3, 8.8, 8.14, 8.17–21, 9.3, 9.6, 9.10–11, 11.11–12, 11.16–19, 11.21, 11.29, 12.10, 13.6–14, 13.17, 14.3, 14.6, 14.8–9, 14.11–13, 14.16, 14.18, 15.10, 15.12–13, 16.4–5, 16.11–12, 17.13, 17.18, 17.27–28, 18.9, 18.14, 18.16, 18.18, 19.10–12, 19.16, 20.2–3, 20.6, 20.14–15, 20.25–27, 20.31–35, 20.38–40, 21.8, 21.10–11, 21.13, 21.16, 21.18–20, 21.25, 21.29–30, 22.13–14, 22.23–27, 22.32–34.

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Part 1

MAKING SEDIMENT

... the soil which has kept breaking away from the high lands during these ages and these disasters, forms no pile of sediment worth mentioning, as in other regions, but keeps sliding away ceaselessly and disappearing in the deep.

Plato, Critias, Vol. 9, Loeb Classical Library

Introduction

The noun *sediment* comes to the English language from the Latin root *sedimentum*, meaning settling or sinking down,aform ofthe verb *sedere*,to sit orsettle. In earth and environmental sciences, sediment has a wide context that includes many forms of organic and mineral matter. In Part 1 we look more deeply at the origins of the sediment that occurs on and under the surface of the solid planets and which may be used to infer past environmental conditions and changes. Sediment accumulations may be grandly viewed as the great stratal archive of past surface environments, or more basically as‘dirt’. There has been sediment on the surface of the Earth since the Archaean, with the oldest known sediment grains dating from at least 4.4Ga (Part 1 Fig. 1). Sediment also mantles the surface of many other planets and their satellites, notably Mars, Venus and Saturn’s moon, Titan.

In scientific usage, Earth’s sediment is best divided into three end-members:

- *clastic*—originating from pre-existing rock outside a depositional area as transported grains, the commonest being mineral silicate grains, known widely *as siliciclastic sediment*;
- *chemical*—being the result of inorganic or organically mediated chemical precipitation within the depositional area;
- *biological*—derived from skeletal material associated with living tissues.

These simple divisions are robust enough to include even the highly esoteric sediment forms that are turning up in the wider Solar System, like the solid ice particles transported and deposited by liquid methane on Titan.Ofcourse there are unusual, hybridormixed origins for some sediment but these can easily be accommodated (e.g. *bioclastic, volcaniclastic*). Note that the classification is restricted to grains that were sedimented; there are sedimentary horizons in the stratigraphic record that originated as precipitates below the deposited sediment surface, often bacteri-ally controlled. These were never sedimented as such and are considered as secondary or *diagenetic* sediments that post-dated physical deposition of host primary sediment. Deposited sediment accumulates as successive layers, termed *strata*, and such deposits as a whole are said to be *stratified*. The succession of strata in any given deposit is controlled by environmental factors and their correct interpretation involves a deep understanding of how present and past environments have evolved over time.

The chemical and biochemical processes that produce sediment also give other soluble byproducts; these chemical species control oceanic and atmospheric composition and provide long-term sourcing for base cations that nourish plant life and counteract acid deposition in temperate forested catchments. Chemical earth-surface processes