Cees W. Passchier
Rudolph A. J. Trouw
Microtectonics

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Preface

The origin of this book lies in a practical course in microtectonics started by Prof. Henk Zwart at Leiden University, the Netherlands, in the early 1960s. Both of us were students of Henk Zwart at the University of Leiden and later, as his assistants, charged with the organisation of this course. As such, we became enchanted by the many interesting thin sections of his collection which expanded over the years, as Henk extended his work from the Pyrenees to the Alps, the Scandinavian Caledonides and to many other places in the world. An explanatory text was elaborated and regularly updated by a number of assistants, including us, under Henk's supervision. This text, together with many thin sections of the collection, served as a core for the present book. In the early 1980s, the Geology Department of Leiden University was transferred to the University of Utrecht. The collection was transferred as well, and one of us (C. W. P.) became responsible for its organisation and maintenance. A visit of R. A. J. T. to Utrecht in 1991 with a number of didactic microstructures collected in South America triggered the final effort to build a manual for the study of microtectonics. Because of his contributions to science and his enthusiasm for microtectonics, we dedicate this book to Henk Zwart, who inspired us, taught us the principals of microtectonic analysis, and also furnished many crucial examples of microstructures.

The first edition of "Microtectonics" from 1996 is now outdated, and we felt that the large amount of new work in microtectonics warranted the setup of this second edition. This edition contains nearly all the old material, but adds material on new research of the last ten years and some material that was left out of the first edition for several reasons. As a result, the number of figures has increased from 254 to 322 and the number of references from 659 to 1451.

Few geologists will be able to remember what their first impression was when they were confronted with a deformed rock under the microscope. That is unfortunate, because it inhibits experienced geologists from looking at geometries in thin section in an unbiased way. We commonly think that we 'see' processes such as dynamic recrystallisation, refolding and grain growth, while all we actually see are geometric patterns that may have formed in a number of different ways. In this book, we try to preserve some of the 'first encounter approach' with deformed rocks and follow some guidelines that result from many years of teaching structural geology. First of all, structural geology and microtectonics are visual sciences, and need good and abundant illustrations to be properly understood. The result will be obvious for anyone who pages through this book. Secondly, there is no harm in explaining features at a basic level rather than in full detail for specialists; specialists can skip simple explanations, but all those who are new to the subject have better access to the content of the book if things are explained in a simple way. Finally, there is nothing more frustrating than to know that a certain subject has been covered in the literature, but not to know who wrote about it. Therefore, we have included a large number of references throughout the text.

The following critical readers of the original manuscript for the first edition helped considerably to improve the quality with useful suggestions: Hans de Bresser, Bas den Brok, Paul Dirks, David Gray, Monica Heilbron, Renée Heilbronner, Ralph Hetzel, Kyu-

ichi Kanagawa, Win Means, Uwe Ring, Herman van Roermund, Luiz Sergio Simões, Carol Simpson, Ron Vernon and Janos Urai. Their help is gratefully acknowledged. Photographs, samples, thin sections and material for the text were kindly provided by Ralph Hetzel, Paul Dirks, Domingo Aerden, Michel Arthaud, Coen ten Brink, Hanna Jordt-Evangelista, Reinhardt Fuck, Leo Kriegsman, Gordon Lister, Leo Minnigh, Jin-Han Ree, André Ribeiro, Chris Schoneveld, Janos Urai, Simon Wallis, Klaus Weber and Dirk Wiersma. For the second edition similar help was given by Scott Johnson, Daniel Koehn, Hans de Bresser, Michael Stipp, Holger Stünitz, Manuel Sintubin, Erich Draganitz, Sara Coelho, Renée Heilbronner, Geoffrey Lloyd, Chris Wilson, Anne-Marie Boullier, Lutz Nasdala, Steve Foley, Michael Bestmann, Giorgio Pennacchioni, Chris Ryan, Martyn Drury, David Ferrill, Vincent Heesakkers, Jens Becker, Nico Walte, Claudio Valeriano, Rodrigo Peternel, Camilo Trouw, Felipe Medeiros, Mauro Torres Ribeiro and Margareth Guimarães. Tarcisio Abreu elaborated high quality thin sections. Many other persons helped in one way or the other, either by providing samples with interesting microstructures that were integrated in our collections but not shown, or by discussing the meaning of microstructures. Their help is also gratefully acknowledged.

The Volkswagen Stiftung, the German Science Foundation (DFG), the Schürmann Foundation, the Dutch Royal Academy of Sciences, the Deutscher Akademischer Austauschdienst e. V. (DAAD) and the Brasilian Research Council (CNPq) provided funding for our research, the results of which have been used in this book; this support is gratefully acknowledged. R. A. J. T. thanks the Brasilian Research Council (CNPq) also for financing his stay at Utrecht University.

About This Book

This book deals with the description and interpretation of small scale structures in deformed rocks as seen in thin section through the optical microscope. The book is meant for advanced undergraduate and graduate students, and is best used in combination with a practical course where thin sections can be studied and discussed. In our experience, a collection of 100–200 thin sections with examples from structures treated in our Chapters 3–9 are sufficient for such a course.

In Chapter 1 the 'philosophy' of how we think that microstructures can be understood is discussed, including their usefulness in tectonic studies. Chapter 2 gives a simplified, non-mathematical background in kinematics and rheology, meant to explain the terminology used in the interpretation of microstructures. Deformation on the grain scale and deformation mechanisms are treated in Chapter 3. Chapters 4 to 7 form the core of the book and deal with the most commonly observed microstructures. In Chapter 8 some primary microstructures from igneous and sedimentary rocks are discussed, and in Chapter 9 a brief outline is given of a new development in microtectonics which we called microgauges: structures that can be used to obtain quantitative data from deformed rocks. Chapter 10 describes a number of additional techniques other than optical microscopy. These techniques either use thin sections, or can be used in combination with optical microscopy to obtain additional data. The descriptions are short but should allow the reader to decide if it is advantageous to use an unfamiliar technique, available outside the home department. Chapter 11 gives an overview of the current state of the art of experimental studies. Chapter 12 describes problems involved with sampling and preparation of thin sections, including the problem of the interpretation of three dimensional structures using two-dimensional sections. A glossary and index are given at the end of the book; the definitions in this glossary reflect our opinion on the meaning of the terminology as used at present. A number of boxes explaining subjects in more detail are present in several chapters. Figures in these boxes are numbered separately, starting with "B." and the chapter number.

Throughout the text, words written in italics indicate items that are introduced for the first time, most of which are explained in the glossary and can be found in the index. In the figure captions, PPL and CPL mean plane polarised and crossed polarised light, respectively. Provenance of the photographed thin sections is given where known. For some thin sections in the old collection from Leiden, the provenance is unknown and these were marked as 'Leiden Collection'. The scale of the photographs is given as a width of view.

The *accompanying CD* contains full colour versions of all drawings and of many photographs in the book, animations of figures in the book and videos of deformation experiments, a number of additional colour photographs, figures from the boxes, an explanation on the use of the U-stage, the glossary and 35 photographs of examples of common problems in microtectonics meant to be used as interpretation exercises. The CD also contains a search option for figure captions and the glossary. Since all figures in the book are also on the CD, there is no separate reference for them in the text of the book. Additional colour photographs of items on the CD which do not appear in the book are marked in the text with '◎Photo'. Where these show similar items as figures in the book, they have been given the same number. Animations and videos are both marked as '◎Video'. If they animate figures from the book or show similar features, they have been given the same number as relevant figures in the book.

C. W. Passchier
R. A. J. Trouw

To see a world in a grain of sand
and a heaven in a wild flower
hold infinity in the palm of your hand
and eternity in an hour

William Blake

Salve, parens rerum omnium Natura,
teque nobis Quiritium solis celebratam
esse numeris omnibus tuis fave

Gaius Plinius Secundus

To Henk Zwart

for his contribution to structural and metamorphic geology

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