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BOOK REVIEWS

Two books on fracture

Atkinson, B. K. (Editor) 1987. *Fracture Mechanics of Rocks*. Academic Press, London. 534 pp. Price £60.00 (hardback).

Quite simply, this is the best research level geological textbook I personally have seen for many years. It is a veritable *tour-de-force* of both geological and geological-related fracture mechanics, comprising contributions from workers (including the Editor himself) at the forefront of modern research in the subject. The book is divided into 11 chapters, most of which could certainly exist as individual monographs in their own right. However, several of the chapters can also be grouped together into distinct sections based on common themes, such as theory and experiment, field evidence, applications, etc. The Editor himself is responsible (either individually or in partnership) for three of these chapters. Although highly individualistic, the different chapters do fit together into a whole which is a joy and pleasure to read. For this achievement alone the Editor deserves credit. Obviously, there is some repetition between chapters, but this invariably helps to reinforce the points being made and also helps the readability of each chapter by reducing the need for constant reference elsewhere. Each chapter represents the most up-to-date review currently available and many also contain hitherto unpublished work by the individual authors. The book is well illustrated throughout and further benefits from the use of reference lists at the end of each chapter. At £60.00 it is undoubtedly expensive, but it is still a must for any geological library or serious research group.

The first chapter is by the Editor himself and serves a dual purpose: to acquaint the reader (particularly those new to fracture mechanics) with the necessary background to the subject, and as a general introduction to the volume as a whole. It is a marvellously erudite and succinct piece of work and deserves to be read and re-read by all geoscientists. Nevertheless, it is merely an appetizer for what follows.

Perhaps Chapter 2 (T. Engelder), which deals with field evidence on crustal fractures, would have been better positioned somewhat later in the book, but this is only a minor and personal view. The author describes joints and shear fractures on all scales from microcracks to continental strike-slip fault zones, although he restricts discussion to the rupture of intact rock rather than the evolution of fault zones over time. The scope of this chapter is potentially prohibitively large, but the author presents an instructive account, with extensive references for further reading.

Chapters 3 (A. R. Ingraffea) and 4 (B. K. Atkinson & P. G. Meredith) are concerned with the fundamental theories and related experimental results on which the analyses of geological fracture problems are based. The former is concerned with fast fracturing whilst the latter considers slow, stable ("subcritical") crack growth. Both include extensive use of natural data and mathematical models, often originally obtained or derived by the authors themselves. Chapter 4 in particular ideally illustrates the importance of materials science concepts to fracture mechanics.

In Chapter 5 (L. S. Costin), the experimental and theoretical basis provided by the previous two chapters is used to develop a general model for time-dependent deformation and failure. It therefore serves to link the earlier chapters to the later ones (which deal with various applications of fracture mechanics) via the formulation of a rigorous physical model. The information presented in this chapter is relevant to all branches and scales of applied fracture mechanics, and also emphasises the relationship which must exist between fracture and continuum mechanics. Initially the treatment is rather simple but it becomes more complex with realization that failure is ultimately determined by various rate-dependent properties which also result in microstructural changes and material damage.

Chapters 6–9 are concerned with the application of fracture mechanics to a variety of geological problems: hydrofracturing and crustal stress measurements (F. Rummel), geothermal energy exploitation (H. Takahashi & H. Abe), natural fractures (e.g. faults, joints, veins, dykes, etc.) in rocks (D. D. Pollard & P. Segall) and the shear fracture mechanics of earthquake zones (V. C. Li). As such, they are likely to have varying appeals, but I would recommend that they are read on their own merit since they each contain a wealth of information which is potentially much more widely applicable. Personally, I found the chapter by Pollard & Segall particularly stimulating and it clearly indicates how fracture mechanics can be applied to various aspects of structural geology. However, I also realized that the other three chapters contained information relevant to my own research interests. Although individually these four chapters are quite superb, and taken together they are even better, I must make special mention of the chapter by Li since it is arguably the best in the entire book. Considering the overall quality of the book, this represents quite an achievement.

Chapter 10 (D. E. Grady & M. E. Kipp) investigates how a system of cracks responds to different loading configurations and hence affects the mechanical properties of a rock mass. This behaviour (which results in dynamic fragmentation) is much less clearly understood than the behaviour of individual cracks and fractures and hence this chapter is perhaps the most individualistic in the entire volume. Nevertheless, many of the concepts, theories, models and observations described in the previous nine chapters can still be recognized. Several examples of real applications (including enhanced oil–shale seepage and the dynamic stimulation of wellbores) are also given. The relationship between fracture and continuum mechanics is again emphasised, as well as the statistical nature of many natural fracture processes.

The final chapter (B. K. Atkinson & P. G. Meredith) is apparently just a tabulation of experimental fracture mechanics data for different minerals and rocks. However, the 27 pages of data represent the result of years of experimental work by different laboratories and are the accepted values of the parameters needed to apply fracture mechanics to geological problems. The collation of these data in one source will therefore facilitate the future applications of fracture mechanics. The data tabulation is preceded by a sort description of the experimental procedures involved in their determination.

As I said initially, I consider this to be the best geological textbook I have had the pleasure to read for many years. The volume is at the same time both general and specific. It contains simple reviews and also much new and original work. Obviously, one can identify some omissions: from my own interests, I would have liked to have seen some discussion of the microstructures associated with fracture mechanics phenomena, particularly as revealed by electron microscopy. But any omissions are almost certainly a consequence of the current state of the science of fracture mechanics, which is still evolving rapidly particularly with respect to real applications. This book therefore represents our current knowledge of fracture mechanics theories and formulations. As geologists, it is up to ourselves, the readers, to go out and apply them. The geosciences community as a whole owes its thanks to the Editor, Barry Kean Atkinson, for the opportunity to do this via this magnificent text.

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Blès, J. L. & Feuga, B. 1986. *The Fracture of Rocks*. North Oxford Academic, Kogan Page, London. 131 pp. Price £18.50 (hardback).

In my opinion there is no text which provides a properly balanced coverage of the subject of fracture of rocks, and the appearance of an English translation of *The Fracture of Rocks* by Blès and Feuga does nothing to change that situation. Part of the problem may be that the original French language edition first appeared in 1981, whilst the intervening years have seen substantial advances in our understanding of rock fracture. However, the present edition is described as being revised and updated.

The book is structured into two large sections, the first subtitled *Concepts of Rock Mechanics* and the second subtitled *Observation and Interpretation of Natural Fractures*. The first section, which comprises half of the volume, is equally divided into a summary of the theories of stress and strain, and a summary of tensile and compressive failure of rocks, including a consideration of the effects of pre-existing planes of weakness. In this book rocks are always considered to be continuous elastic solids, and thus their granular nature and its consequences are ignored. It is debatable whether it is necessary to repeat stress and

strain theory in texts on structural geology and rock deformation. In this book the theory of strain in particular is not given in a form which is very useful to geologists.

The second section deals with a number of very specific points, to each of which a chapter is devoted. The general point is made that fracturing is characteristic of upper crustal deformation, and for the purpose of subsequent description, "geological fractures" are categorized according to whether they are joints, tension gashes, stylolites (!) or faults. A description of the geometric characteristics of each and its mode of origin are then given. The reactivation of arrays of variously oriented fractures and the use of their orientations and the orientations of slickenlines upon them to infer the principal directions of the bulk displacement field are described (probably for the first time in a textbook). Geometric characteristics of small fractures commonly associated with large faults are then discussed, and the book is concluded with a description of the commonly observed relationships between fold geometry and fault and joint arrays.

A more balanced treatment of brittle failure of rocks might include an outline of the theories of stress and strain, a description of experimental techniques used in the study of rock fracture, an outline of the principles of fracture mechanics, and the phenomenology of rock failure in compression, including the effects of dilatancy and the evolution of microstructure. A considerable amount of space should be devoted to rock friction, the localization of faults and their structural and microstructural characteristics, especially in view of the attention that subject has received in recent years in connection with earthquake hazard reduction. The failure of rocks in effective tension and the phenomenon of hydraulic fracture should receive special attention.

Various other texts also give emphasis to particular topics from this list. For example, Paterson (1978) gives a comprehensive review of experimental studies of brittle fracture, whilst the recent compilation of papers edited by Atkinson (1987) gives an overview of the application of fracture mechanics in geology and geophysics. Blès and Feuga make no mention of the concepts of fracture mechanics.

There is also a 'traditional' kind of approach to the treatment of rock fracture exemplified by Jaeger and Cook's *Fundamentals of Rock Mechanics*, in which rock failure is described entirely in terms of the applied state of stress, without reference to the microstructural changes which characteristically accompany progressive failure. In the latter text and others like it, an idealized 'Griffith fracture' approach is developed (although there is in fact little microstructural basis for doing so), but Blès and Feuga do not explore this avenue at all. The application of the Griffith energy balance concept via the Irwin fracture mechanics approach represents the only sound basis for a theoretical description of rock failure, but this is typically lacking in presentations of rock mechanics for consumption by structural geologists at this time, including the present volume.

In many of the above respects, therefore, I find the book of Blès and Feuga to be deficient. On the other hand, it would be unreasonable to expect a comprehensive coverage in such a small volume. Provided the reader is aware of its limitations, it provides a useful overview of a number of topics in rock fracture. One very positive aspect is that the translation into English is excellent and thoroughly readable.

It is not made specifically clear to what audience the book is directed. Most structural geologists will be familiar with the majority of the material, and will find several of the sections elementary. For example, the whole chapter which is devoted to relationships between fractures and folds, and the description of characteristic structures which develop at different depths within the crust, would be appropriate to first or second year undergraduate courses in geology. As a course book, I would think the text is most suited to undergraduate students of civil or mining engineering taking a course in geology.

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Jaeger, J. C. & Cook, N. G. W. 1976. *Fundamentals of Rock Mechanics*. Chapman and Hall, London.

Paterson, M. S. 1978. *Experimental Rock Deformation; The Brittle Field*. Springer, Berlin.

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Structures in granites

Marre, J. 1986. *The Structural Analysis of Granitic Rocks*. North Oxford Academic, Kogan Page, London. 124 pp. Price £18.50.

(Translated, revised and updated from the original French language edition first published in 1982.)

This slim, hardbacked volume is one of a series of BRGM publications which have been republished in English by North Oxford Academic. Although presenting itself as a type of handbook on the description and interpretation of deformational features of granitic rocks and the relationship to emplacement mechanism, the breadth of investigation implied by the title of the volume is not found in the contents. The text is principally concerned with structural features formed in granitoids prior to their full crystallization and much of this is interpreted, following the earlier work of Cloos and Balk to be the result of flow of magma into emplacement spaces. Crystal plastic strain fabrics and brittle deformation are only dealt with where these are considered to be continuations of the "magmatic flow processes". The book is therefore quite narrow in both its scope and its interpretations.

The text is presented in three basic sections whose organization follows closely that of the classic Balk memoir and commentary on Cloos's work *The Structural Behaviour of Igneous Rocks* (1937). Part 1 deals with the microscopic description and interpretation of textures and fabrics: the recognition of magmatic textures and their modifications by crystal plastic strain and deuteric activity; the recognition and recording of fabrics and sub-fabrics and their relationship to different types of strain ellipsoids and to progressive deformation; the interpretation of the fabrics as phenocryst/crystal laden suspensions deforming in magmatic flow (the latter regarded by Marre as a purely simple shear process).

Part 2, which deals with macroscopic structures, forms the bulk of the book and is divided into flow structures, joints, contacts and enclaves. "Flow Structures" treats the description and interpretation of "platy" fabrics (including schlieren), "combined linear and platy" fabrics and "purely linear" fabrics (what other modern texts would probably refer to as S, LS and L fabrics), together with more complex situations. In the section on joints, Marre again follows Cloos in asserting that where aplite and pegmatite filled joints form in orthogonal and parallel relationship to LS flow fabrics, the joints are a "continuation" of the flow deformation: although as with this earlier work the mechanical basis for this relationship is not well understood. Igneous enclaves are divided into "elongate" and "angular". Elongate enclaves are shown to have low viscosity contrasts with the host granite and are considered to have been "liquid" at the time of deformation with the host enclave system representing evidence for a partially mixed magma. The invariably good parallelism of these enclaves is interpreted to be the result of "a shear strain of considerable intensity" (p. 67). Angular enclaves have high viscosities relative to the host, were crystalline at the time of incorporation and were, according to Marre, produced by the explosive fragmentation of the parent rock.

Part 3 on megascopic analysis (essentially plutons as a whole) begins by comparing model studies of magma emplacement with "flow patterns" in plutons themselves. This emphasizes that the orientation and strength of flow structures reflects the shape of the pluton contacts ("the nearest friction-exerting surface" of Cloos) and these in general should be dome-like. Variations on this pattern can be attributed to coeval magmas of differing viscosity creating perturbations in the flow lines. The final section analyses, using the methodology described, examples of different plutonic complexes: the inflation by successive magma injection of the Ardara granite of Donegal; the vertical ascent and lateral spreading of the much quoted Querigut complex in the Pyrenees; the roof collapse/cauldron subsidence and injection of low viscosity melts associated with the Rosses and Barnesmore granites of Donegal; the ballooning emplacement of the Spanish Sierra Morena plutons into synchronous regional shear zones and finally the varying emplacement mechanisms of a Variscan batholith in Corsica.

On the positive side, this book is short, well laid out and well illustrated (although there are no photographs). Of all the sections in the book I found that on microscopic structures the most useful in that it emphasizes the possibility of determining the progressive-deformation history and rheological changes through the orientation distributions of sub-fabrics in any given granite. The author's continual exhortations to examine and describe rocks carefully before interpreting them is to be applauded.

On the negative side I found many of the sentences badly constructed and difficult to understand (although this may partly reflect