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BOOK REVIEWS

Pondering mechanics of structures

Bayly, B. 1992. *Mechanics in Structural Geology*. Springer, Berlin. Price DM 68 (softback)

One of the 'perks' of being an editor is having a first look at all the new books that come in for review. Occasionally, one arrives that is so close to my own interests that I am tempted to review it myself. This is the case with *Mechanics in Structural Geology* by Brian Bayly, a welcome soft-backed book at an affordable price.

The book cover claims this to be an innovative textbook for students and a reference book for all geoscientists concerned with geological structures. It presents fundamental concepts necessary to understand deformation of the Earth's crust. The author's Preface reveals his own philosophy and that behind the book, and includes some notes about how the various sections of the book are organized, and might be cross-related. This is aided by a pictorial plan on the inside front cover. The inside back cover is a useful reference page on Units.

Chapter 1, the Introduction, is just 2 pages introducing mountains in terms first of human affairs and then mechanics. This might have been equally at home in the Preface; or alternatively, to have been a fuller introduction to concepts in mechanics.

Chapter 2, Strains and Displacement, deals with linear strain, shear strain, laminar materials, strains from point to point, and Mohr circles, in turn. Strain is introduced clearly, but I have some reservations about the treatments of area stretch and strain, and volume stretch and strain (pp. 9–11). These are expressed in terms of mutually orthogonal directions (S_1, S_2, etc.), which are not defined as principal directions: indeed, principal values are not introduced until later on. Surely, the product of *any* three orthogonal stretches does not define the volume stretch? The Pyrenees is introduced as an example, and is returned to in later examples in the book. A theme throughout this chapter (and in the next one, on stress) is the change in value of strain with direction, as illustrated by sinusoidal curves of linear or shear strain vs direction. The attention given to the maximum shear strain at 45° to the maximum linear strain (pp. 20–21), should, perhaps, make it much clearer that this is only the case for strain rates or small strains. I suspect many might think Fig. 2.20 refers to finite strains.

The section on laminar materials in fact deals with simple shear. This is one of several examples of where Bayly's nomenclature seems unnecessarily different from terms accepted in structural geology. Interestingly, although the subsection "linear strain in laminar behavior" does not emphasize that simple shear is being introduced, "simple shear" is given in the Index with reference to these pages (pp. 26–29). The subsection dealing with change of strain from point to point introduces heterogeneous strain in folded layers. The Mohr circle is presented in a fresh way at the end of the chapter, and applied to strain partitioning.

Forces and Stresses are the topics for Chapter 3. Forces are related to daily life, and many examples are used to introduce concepts such as force balance and stresses at an interface. I confess that I did not work through every question and answer in detail, and did wonder how many students would. Many of the important concepts are actually revealed in these examples, although Bayly usually reiterates them later in the text, and in the useful summary sections. Chapter 4 deals with Variation of Stress with Direction, a short chapter which might have been better incorporated with the previous one. Stress on oblique planes, and stress refraction across interfaces, are investigated here, although refraction is not actually derived or illustrated in the text; it appears in the answer to question 4-12.

Chapter 5, Rheology: Relations Between Forces and Material Response, is probably the most far-reaching and detailed chapter. Here, Bayly investigates viscosity for geologically realistic situations, multilayer deformation and folding, and ends with changes in volume—a treatment of permeability, pressure solution, etc. We are really into the meat of the book, and a large number of examples, some quite difficult, are used to get points across. I had some personal difficulty with Bayly's geological time unit, gtu, and geological viscosity unit, gvu, both new to me. (1 gtu = 10^{14}s = $3\frac{1}{4}$ my; 1 gvu = 1 MPa gtu = 10^{14} MPa s.) Whereas these units may have been designed to make the examples easier, I could not get the feel of them, and found them awkward. The subsection "a rock has variable viscosity" is thought-provoking, though Table 5.5 was tortuously difficult, and I did wonder whether the numerical examples might make some readers think that the values used were geologically true. Bayly states (p. 127) "it is helpful to keep in mind the way a rock's viscosity can vary and the largeness of the viscosity's range". However, interesting as this statement is (and probably true), there is nothing in the book that actually verifies what is, essentially, a speculative statement. Refraction is considered again in this chapter, in terms of strain, markers and cleavage. Bayly suggests that the ratio of shear strain across a boundary provides a robust indication of viscosity ratio. I have considerable reservations about this as a *general* statement, with no reference to rheology or type of deformation. (It is, of course, central to my own work, so perhaps I am unduly nitpicking.) The last section, dealing with fluids in deformation, is very useful, particularly as this is often treated scantily in other texts. It might perhaps have been a small chapter in its own right.

"Parting" is the title of Chapter 6. Bayly used this term for discontinuous deformation, or fracture. I do not see why he did not use "flow" for the previous chapter, and "fracture" for this one: terms he considers in combination in the final chapter. Parting conjures up images of shales, or hairstyles (or ".. such sweet sorrow"), for me. That quibble apart, I liked the introductions to shear and tensile parting; and to the Mohr envelope, although Bayly makes little attempt to explain *why* rocks fail in shear in a certain direction (and coefficient of friction is not described until later). I was unimpressed with the classification of faults on p. 174. Surely a diagram would have been better than words; and is "slide" the appropriate name for a low angle normal fault? This chapter gives considerable attention to wedge-shaped thrust sheets, and these certainly serve to illustrate many important mechanical principles. I would have liked more discussion on the mechanics of fracture propagation and interaction in rock-like materials, and perhaps something on seismic processes to link with Bayly's reference to earthquakes in the chapter's introduction. However, his emphasis on the role of fluids in fracture processes, and the message that parting is a fluid-assisted process in a viscous material, are valuable. This section might prove quite challenging for students and non-specialists. I was puzzled by the sudden introduction of a power flow law on p. 186, without justification—and not having been introduced earlier, to my recollection. However, the discussion of effective stress is comprehensive and thought-provoking.

The final chapter (7) considers Concurrent Fracture and Flow. It attempts to treat the deformation of rocks in a realistic and far-reaching way. Though I found it highly stimulating, it might prove difficult for some students. Much is brought together in 'grand finale' diagrams like Fig. 7.4, showing schematic deformation regimes with depth, temperature, pressure, for thrust, strike-slip and normal fault regimes. These might have been helped by captions, rather than discussion within the text. The chapter concludes with the Pyrenees, again with some rather complex diagrams of deformation fields that could prove challenging to many readers.

There is one place in this last chapter where I think there is an incorrect or misleading statement. Reintroducing the Mohr diagram for stress to represent flow behaviour (p. 209), Bayly suggests that to show stresses on all planes passing through one material point "requires a complete circle of points in the [Mohr] diagram". This is certainly not true for the usual three-dimensional Mohr stress diagram. Only planes passing through principal stress axes will plot as points on a full circle (a principal circle). Planes through other material lines will occupy various curves in the region between the three principal circles, analogous to the Mohr loci described for Mohr strain diagrams. This misleading statement about the Mohr diagram does not appear to be further developed, or lead to any serious problems. However, I mention it because it seems to be an example of confusion between two different applications of the Mohr diagram for stress: (1) to illustrate a single three-dimensional state of stress in a triaxially stressed body; and (2) to illustrate successive states of stress in a material, for example at failure, where only the max/min stress circle is represented (i.e. two dimensions). Bayly's Mohr diagram for flow behaviour must be of the second kind, and yet his introductory words talk of states of stress, and planes, which are more suggestive of the former.

Five appendices conclude the book. A–C concern abbreviations, precision, and weights as units of force. D discusses experimental work on rock deformation in a philosophical way. Appendix E, Books on Related Material, lists nine textbooks which deal with relevant topics at a general level. I was surprised that Biot's *Mechanics of Incremental Deformations* (1965) was not among them (my own personal bible).

The general question of whether textbooks should contain references, either to source material or to further reading, is clearly open to debate. In the case of this book, I think that the lack of references is a shortcoming which will prevent many readers from going much further than the ideas and applications presented. Parts of the book are innovative, and seem to contain ideas not presented in the research literature: or at least not in that way. However, there are other places where Bayly is presenting well-examined topics, or rederiving principles developed by others, and there is no easy way that a student could know which were which. Thus, Bayly's original approach has the downside that he is ploughing his own furrow, in parallel with considerable bodies of research in structural geology, and with no cross-ties. There are examples, as noted above, where idiosyncratic terms have been used instead of those in common parlance. But perhaps the greatest problem arising from the combination of his original approach and the lack of reference to relevant research papers is that readers are left with nowhere further to go. It would, of course, be an enormous task to include references to the many relevant papers in structure and tectonics which are based on the principles of mechanics outlined in the book. Nevertheless, I believe such an addition would add enormously to the book's educational value.

In conclusion, I found Brian Bayly's book well written and nicely produced, with a commendable absence of typographic errors. The illustrations are good, though descriptions of the figures in the main text, rather than in figure captions, could lead to a few difficulties. In any text as comprehensive as this, there are bound to be differences in emphasis that some teachers would give to particular topics. However, one of the charms of this book is that it *is* different from both structural geology text books and mechanics texts. Bayly has brought these two fields together admirably, with great intelligence, imagination and originality. For this reason alone, I think all active structural geologists, whether in research or teaching, and particularly those concerned with theory, should read this book. They may not agree with everything in it, but it will certainly make them think about the principles behind geological structures and tectonics.

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Fluids and subduction

Tarney, J., Pickering, K. T., Knipe, R. J. and Dewey, J. F. (editors) 1991. *The Behaviour and Influence of Fluids in Subduction Zones.* The Royal Society, London. 192 pp. Price £37.50 ($69.95).

Fluids are becoming recognized as having a major influence on geological processes at all levels within the Earth. Whether studying deformation history, metamorphic processes, mineralization phenomena or magmatic evolution, the influence of fluids is ubiquitous. Perhaps nowhere are fluids more intimately involved in geological processes than in subduction zones where wet sediments and hydrated ocean crust are either accreted to the overriding plate or dragged deep into the mantle. They represent places where water is recycled back into the mantle and hence fluid behaviour is significant not only for the workings of a subduction zone but also for the geochemical balances within the Earth as a whole. The present book is therefore a timely contribution to a subject of increasing geological interest.

The book is a collection of papers first presented at a discussion meeting of the Royal Society held on 8th and 9th of November 1990. The papers were originally published in the *Transactions of the Royal Society, Series A*, Volume 335, and have now been re-issued in book form. In fact, the page numbers of the original journal have been retained so that it was with some consternation that on reaching the end of the first article, I found myself on p. 242! Consecutive book pages have been added in parentheses, however. In the words of the editors, the collection is intended to serve as both a review or synthesis of what recent research has achieved, and a stimulus to further research by highlighting a number of directions requiring more attention.

The book contains 13 separate articles covering accretion of unconsolidated sediment to the geochemical evolution of the mantle. The articles nevertheless fall broadly into two distinct groups. The first group, of seven papers, is concerned with the fluid flux through the accretionary prism as observed in modern forearcs. The second group of six papers is largely concerned with the release of volatiles from the subducted slab within the mantle and the production of magmas. There is really very little in common between these two groups, although Peacock's interesting paper on the numerical simulation of subduction zone pressure–temperature–time paths acts as something of a bridge between the shallow and the deep processes.

Within the first group of papers, some are written essentially as reviews whereas others are largely vehicles for presenting specific data. Westbrook gives a clear synthesis of geophysical evidence for fluid flow in accretionary prisms, while Kastner *et al.* provide a thorough review of the geochemistry of fluids in modern prisms, stressing the problems of identifying the various sources of fluids. Le Pichon *et al.* present calculations of predicted fluid fluxes from compaction of wet sediments and dehydration of hydrous minerals at depth, and compare these with measurements of fluid fluxes on the Barbados, Central Oregon, Northern Cascadia and Nankai subduction zones.

All three papers conclude that measured fluid fluxes are much greater than predicted from compaction and dehydration. In the case of the Nankai zone, Le Pichon *et al.* suggest shallow level sea-water convection is important, but in other zones, large fluxes of low Cl^- fluids require a deeper and prolific source of water. It seems clear that much still needs to be done before fluid budgets of accretionary prisms are understood.

Moore *et al.* present a thought-provoking paper on the influence of variable porosity and permeability on fluid flow, comparing the muddy Barbados Ridge complex with the sandy Oregon prism, and Knipe *et al.* provide a thoughtful review of the microstructure of DSDP samples from accretionary wedges, posing some provocative questions regarding deformation processes in these environments. Finally in the first group of papers, Taira and Pickering give a relatively detailed comparison of fluid flow and structure of the Nankai, Izu-Bonin and Japan Trench subduction complexes. Overall I thought the chapters had been well chosen by the editors to give a thorough review of the present understanding of fluid expulsion during early accretion of sediments in subduction zones.

The second part of the book I thought perhaps less satisfactory, maybe because so much has been written on arc volcanism or perhaps because I am not an igneous petrologist. Peacock's paper, as mentioned earlier, explores the effect of a wide range of parameters on the thermal structure of subduction zones while Davies and Bickle present a one-dimensional model of a melt generation column. The remaining four papers attempt to address the origins of the distinctive geochemistry of arc volcanics. Hawkesworth *et al.* present a well-written and lucid review of the trace element and isotope characteristics of subduction-related magmas, addressing the question of how much influence the slab has on the chemistry of the melt; and Saunders *et al.* discuss the problem of LIL/HFS element anomalies of arc volcanics and present a model for their production. Both these papers conclude that induced convection in the mantle wedge above the slab is necessary for magma generation.

Ayers presents experimental data on the solubility of apatite, rutile, monazite and zircon in water of various composition at different pressures and temperatures, and finally McDonough argues for a 10% partial melting on the top 2 km of hydrated ocean crust, leaving a Nb and Ti enriched eclogite to accumulate in a deep mantle reservoir, thus changing the long-term geochemistry of the mantle.

The book is well produced with very few typographic errors. Some of the diagrams are rather small, requiring a handlens to read the lettering, probably due to the reduction in page size from A4 to B5. In these days of word processors and spelling checkers, it is interesting that errors are of a different type than in the past. Whole words get omitted, and rather than misspelt nonsense words, inappropriate words get through. "Drilling sights" and "isotopic radios" were two that brought a little light relief, no doubt both passing through the spelling checker with flying colours!

The final question is: who is going to buy this book? At £37.50 for 190 pages of reprinted articles, it isn't cheap. As a collection of papers,