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Book Reviews

Fault mechanics

Mandl, G. 1988. *Mechanics of Tectonic Faulting: Models and Basic Concepts*. Elsevier, Amsterdam. 407 pp. Price $79 (hardcover).

This is the first publication in a series, *Developments in Structural Geology* edited by H. J. Zwart. It presents a highly individual approach to the vast subject of tectonic faulting, being based largely on the extensive theoretical and experimental studies of fault systems carried out by the author and his colleagues at the Koninklijke/Shell Exploration and Production Laboratories in The Netherlands. It is perhaps the first major attempt to write a comprehensive mechanistic account of faulting in the Earth's crust since E. M. Anderson's text, *Dynamics of Faulting* (Oliver & Boyd, Edinburgh), first published in 1942. The book assumes a working background knowledge of structural geology, tectonics and continuum mechanics, and will be most useful to advanced undergraduates or above.

At the outset, however, it must be said that the very title of the book is somewhat of a misnomer. Here, you will look in vain for any discussion of the major transcrustal fault systems that define the different types of plate boundary, and their deep structure. Nor will you find any discussion of the actual manner in which active faults move, whether seismic or aseismic, and the varying degree of activity they exhibit (time-averaged slip rates ranging over at least four orders of magnitude). Indeed, plate tectonics is given only the barest of mentions at perhaps three or four places in the text. Unsurprisingly, given the background of the author, there is a strong slant towards the interpretation of fault systems developed in sedimentary cover sequences; so much so that a more appropriate title might be *A Soil Mechanics Approach to Faulting!*

The book follows a somewhat unusual format, being divided into two parts. Part I (*Tectonomechanical Models*) follows an almost *Andersonian* lay-out where, after an *Introduction*, there are chapters of *General fault features*, *Extensional faulting*, *Wrench faulting* and *Thrusting*. Part II (*Basic Concepts*), though slightly longer, may almost be viewed as a series of detailed appendices forming the justification for discussions in Part I. It has chapters on *Stress*, *Stress equilibrium*, *Stresses in porous rocks*, *The stress circle*, *Strain* (here, only infinitesimal strain theory is dealt with to any extent), *Poroelasticity*, *Plasticity of rocks*, *Work*, *Buoyancy in porous rocks* and *Flow through porous rocks*. Individual chapters are followed by discussion notes and, occasionally, by recommendations for further reading. Regrettably, this format leads to a somewhat cumbersome system for cross-referencing figures, equations and different sections of the text.

The basic theme throughout is the interpretation of the stress controls on faulting through a continuum mechanics approach employing the concept of *frictional plasticity*, here defined as pressure-sensitive, energy dissipative, strain rate-independent failure in accordance with the Coulomb limit condition. Many will find the simple equation made here between elastic/frictional-plastic failure and brittle behaviour highly questionable. To avoid confusion, readers familiar with other usages of plasticity (crystal-plastic behaviour, general plastic flow at constant stress beyond yield) would do well to acquaint themselves thoroughly with this concept of frictional plasticity (Sections I.1.3, II.7.1 and II.7.4) before proceeding further through the book. Throughout the text, extensive use is made of Mohr circle methods for two-dimensional stress analysis, including some (to me, at least) novel techniques involving the construction of stress poles (Section II.4.2). The serious reader should also take the time to gain a thorough mastery of these techniques at an early stage.

The author goes to great lengths to justify this frictional-plasticity approach, but I find his arguments less than totally convincing. In several places he carries his soil mechanics analogies further than I believe is necessary, referring, for example, to extensional and compressional stress regimes as *active* and *passive limit states*, respectively. While it is clear that the basic approach has tremendous relevance to poorly consolidated sedimentary sequences, its application to lithified sediments, crystalline basement rocks and those deeper portions of the crust where flow mechanisms sensitive to strain-rate and temperature become dominant, is debatable. I find it rather disturbing that so little mention is made of information gained from laboratory studies of 'hard-rock' mechanics. For example, one can read the entire book without gaining any idea of the restricted range of frictional coefficients characterizing sliding rock interfaces (Byerlee's law). Nor is there any serious mention of the numerous time-dependent effects associated with rock failure or frictional sliding. The concepts of modern fracture mechanics, which have special relevance to such effects, are not discussed.

Perhaps the most disappointing aspect of the book, however, is the essentially quasi-static approach to faulting that it presents. As with Anderson's classic text, there is a strong emphasis on the stress conditions for fault *initiation* in intact rocks. The clear message from seismology and plate tectonics, that faulting in the upper part of the earth's crust is an inherently dynamic process with most displacement accomplished by seismic slip increments on existing faults, is largely ignored. In the one discussion of seismic slip processes that I found (Section II.8.3), the impression given is that earthquake rupturing on faults is the exception rather than the norm! From this viewpoint, the book neglects the vast body of information on fault processes that has been gained from detailed studies of active faults and earthquakes in the last decade or so. For example, there is no mention of *characteristic earthquake behaviour*, with its important implications of structural controls on rupturing. On another tack, the discussion of large strain theory is minimal, and its application to understanding the structural evolution of deep crustal shear zones is almost totally neglected. Moreover, in the context of laboratory modelling where very simple basement fault configurations are often employed to give rise to complex patterns of faulting in the cover, I note from my own field experience that ductile shear systems in basement rocks are likely to be of comparable complexity to the high-level fault systems.

On the plus side, however, the book does explore many important topics not usually covered in standard texts on structural geology. Among these, the discussions of poro-elasticity, the effective stress principle, and fluid flow through porous media are particularly useful. The very thorough treatment of stress theory and its application to a vast range of fault structures and settings is also welcome. Many of the arguments are extremely thought provoking, one simple example being the principle of energetic admissibility for interpreting fault offsets (Section I.2.1). The book succeeds best in its comprehensive discussions on the evolution of different fault systems in sedimentary sequences, where the frictional-plasticity concepts are most clearly applicable. In such cases, theory is reinforced by the very fine analog modelling of fault patterns carried out by the Shell research group. Illustrations from this model work shed a lot of light on the three-dimensional structure of fault systems. I particularly enjoyed the thoughtful discussions on the development or non-development of conjugate fault arrays, on the various factors that contribute to the development of listric faults (either syn- or post-failure), and on the different modes of antithetic faulting. This last topic brought to me a new awareness of the important role played by fault-parallel normal stress, a factor which is neglected in standard structural texts.

In terms of presentation, the book is well printed on glossy paper and attractively bound. Line diagrams are generally clear, but many of the photographs are poorly reproduced and not very illustrative. Unfortunately, as is so often the case with Elsevier publications, the text is riddled with typos (e.g. absense, fossile, cicle, perpendiculary, strenght, Tectonincs, Flow through Procks, to quote but a few). A half-page list of errata was included but failed to account for more than a small fraction of the errors I found. One may legitimately question whether Elsevier ever proof-read their very expensive books; have they not heard of computerized checking of spelling?

In summary, while the text is of somewhat limited application and neglects the fundamental dynamic aspects of faulting in the Earth's crust, it still has much to offer the general structural geologist. Unquestionably, it is a book the reader has to work on, and work hard. To paraphrase Mark Twain, "Many of the statements was interesting, but tough!". It served the very useful purpose of making me consider faulting afresh through the eyes of an engineering physicist, in many cases leading me to reassess my own interpretation of common fault phenomena.

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The Ramberg Volume

Talbot, C. J. (editor) 1988. *Geological Kinematics and Dynamics*. University of Uppsala Bulletin of the Geological Institutions, Uppsala, Sweden. 193 pp. Price 155 SKr (*ca* £17).

This volume contains papers from a 1987 conference held in Uppsala in honour of Hans Ramberg, on the occasion of his 70th birthday. Ramberg's brilliant research in petrology and structural geology has always circumvented conventions, and this volume does too, in three respects. It was published, not by a mainstream, international journal (as it well could have been), but by Ramberg's home institute, the University of Uppsala. One opens the volume and who should be author of the first paper but Ramberg himself! Compounding these novelties, my copy arrived with a loose-leaf Table of Contents and Preface (which I have now resourcefully taped inside the front cover). Editor C. Talbot explains in his Preface that the decision to publish in the local bulletin was taken "with the agreement of the authors . . . [and] . . . on the assumption that important work will surface however obscure the source". The papers are indeed important, so I will use this space to help them "surface", by listing the authors and their subjects so readers may write for reprints or perhaps order the whole volume. At the prices shown above, the volume is a bargain, compared with special issues from commercial publishers. Some readers may discover the Uppsala bulletin in their own libraries; it is circulated to six or seven hundred institutions internationally.

Ramberg (University of Uppsala) leads the first section, *Theory*, with the first description I have seen of the energy principles that govern the competition between independent processes in deforming bodies, with examples from buckle folding and nappe spreading. W. S. Fyfe (University of Western Ontario) reviews what we know of geochemical fluxes from the solid earth into the biosphere and concludes that such fluxes can be important on a human time scale and need to be better understood. P. H. Reitan (State University of New York at Buffalo) considers the problem of heat supply in orogenic/metamorphic belts and concludes that a significant contribution from strain heating is indicated. M. B. Bayly (Rensselaer Polytechnic Institute) propagates an idea from Ramberg about the direction-dependence of chemical potential in stressed solids, and manages to define shear stress in terms of a gradient in chemical potential with respect to orientation. J. Huang and D. Turcotte (Cornell University) describe a self-similar mechanical model for an earthquake source region which, when stressed to failure in their computer, yields shock sequences similar to natural seismic sequences. O. Stephansson (Luleå University) surveys available bedrock stress measurements in Scandinavia and concludes that a horizontal component due to ridge-push may be present. J.-P. Poirier (Institut de Physique du Globe, Paris) reviews several kinds of analog studies currently in use by students of rock deformation, noting their usefulness and limitations and giving advice for new work.

In section two, entitled *Fabric Studies*, B. Ildefonse and A. Fernandez (Université Claude Bernard-Lyon I, Université Clermont-Ferranc II) describe simple shear experiments with high concentrations of elongate rigid particles in a flowing matrix. Interaction between the particles is found to slow down their rotation, and to promote a metastable preferred orientation in the shear direction. A. Fernandez discusses the theory of strain-induced preferred orientation of elongate rigid objects, and presents strain maps obtained from feldspar orientations in a granite pluton. W. Schwerdtner, J. van Berkel and J. Torrance (University of Toronto; Free University, Amsterdam; Heath Steel Mines, Newcastle, New Brunswick) describe shape fabric patterns in naturally deformed nodular anhydrite and wrestle with the problem of determining strain history from total strain measurements. P. Hudleston and J. Tabor (University of Minnesota, Minneapolis) conclude the section by describing folded calcite veins and using features of vein morphology and strain analysis to build a tight case for buckle folding with inner-arc collapse by volume-loss.

In the next section on *Numerical Model Studies*, H. Schmeling (University of Uppsala) describes computer models of buoyancy tectonics driven by various combinations of thermal and compositional density inversions, helping to define conditions under which single or multiple cycles of overturn occur. J. van Berkel (Free University, Amsterdam) follows with a two-dimensional finite-element calculation of the strain field in a diapiric ridge and its overburden, and finds the results in general agreement with the results of other computer models and centrifuge experiments.

The final section of papers is entitled *Material Model Studies*. G. Peltzer (Institut de Physique du Globe, Paris) describes indentation tectonics experiments carried out using an enormous centrifuge and samples with a free surface for lateral extrusion of fault wedges. Toward the end of experiments, shortening is found to be accommodated by about 30% vertical thickening and 70% lateral extrusion. P. Davy and P. Cobbold (Université de Rennes) describe non-centrifuge experiments otherwise broadly similar to those of Peltzer, but with varying degrees of lateral confinement at the relatively free lateral surface, resulting in varying ratios of thickening to lateral extrusion. Serial lateral extrusion of fault wedges, observed in the experiments of Peltzer, is not observed here. Cobbold and Davy review geological and geophysical data bearing on the tectonic history of Central Asian over the past 50 Ma and make comparisons with features of their indentation models. J.-C. Soula, G. Bessiere and G. Herail (Université Paul Sabatier, Toulouse; Université de Toulouse-Le Mirail) describe the structural behaviour of physical models consisting of a rigid or ductile basement material overlain by a more brittle cover layer, with pre-existing faults built into the basement in some of the experiments. The behaviour of the cover over these reactivated basement structures is related to the behaviour of the Bierzo basin, Spain. N. Mancktelow (ETH-Zentrum, Zurich) ends with a detailed account of rheological measurements on paraffin waxes, with attention to such inconvenient but important features as variation in properties between different batches of the same wax. Paraffin waxes appear to be useful analogs for geological materials that exhibit a power-law relationship between stress and strain-rate.

The volume may be obtained from the distributors: Almquist and Wiksell International, Box 638, S-10128 Stockholm, Sweden.

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Geology of the North Atlantic and Europe in words and pictures

Ziegler, P. A. 1988. *Evolution of the Arctic–North Atlantic and the Western Tethys*. AAPG Memoir 43. AAPG, Tulsa, Oklahoma, U.S.A. 198 pp. Price $48 ($58 to non-members), carriage extra.

When we were students, my friend, Len Pile, and I used to quip about writing the definitive stratigraphic textbook, to be called *The Geology of the World*, as an antidote to our interminable stratigraphy lectures. Well, Len, if you're reading this I have some bad news—we've been pipped to the post by Peter Ziegler.

This is a much slimmer volume than its title would suggest, for the whole later Silurian to Recent development of the Arctic, Atlantic and European mega-region has been compressed (if that is an appropriate term) into less than 200 pages, supplemented by 30 superbly printed palaeogeographic maps and stratigraphic columns in plate form, in a separate part of the Memoir. Len and I would never have succeeded anyway; this Ziegler/Shell compilation is clearly the product not only of one of the few geological minds capable of synthesizing such an enormous amount of information, but also of what must be the most extensive collection of data available for the region. In this memoir, Ziegler cites some 1200 references to supplement Shell's not inconsiderable in-house database.

The text is organized into 10 chapters, nine of which deal with the whole area for some stated time interval. Within each chapter this vast geographical area is discussed, basin by basin, although there is no obvious consistency in the choice and extent of the basins under discussion from chapter to chapter. This is understandable given the extent of the database which has been winnowed down, but it does mean that if you want to follow the evolution of any particular basin from Palaeozoic through to Tertiary times you often have to search