Crustal rotations from palaeomagic

Kissel, C. and Laj, C. (editors) 1988. *Palaeomagnetic Rotations and Continental Deformation*. Kluwer Academic Publishers, Utrecht, The Netherlands. 516 pp. Price Dfl 240, $129, £78.

Classical methods of structural and tectonic analysis are virtually incapable of detecting rotations about vertical axes, and are of very limited value in determining displacements. Palaeomagnetism has therefore been crucial not only in proving the reality of large-scale relative motions between continents, but also in the discovery of large differential rotations of crustal blocks in zones of intracontinental deformation. An increasingly pressing problem has been to explain how the rotations and displacements determined by palaeomagnetism have been accommodated by the visible structures, and a NATO workshop was therefore held in Greece in May 1988 to bring together field and theoretical structural geologists with palaeomagnetists for the purpose of mutual education and exchange of ideas. The meeting was evidently a success: this book, which comprises the proceedings, contains many useful and interesting papers, and is certainly a must for any departmental library.

That said, I would emphasize that the book suffers from many of the problems common to proceedings volumes. The quality of the papers is very variable, and some should not have been included. I have the strong impression that no attempt was made at peer-review: even the better papers contain errors that should not have passed the most rudimentary review or editorial procedures: inadequately labelled figures, undefined symbols, mistakes of syntax, and passages of text that simply do not make sense. The lack of editorial attention presumably allowed the rapid publication time of the volume, which appeared within seven months of the meeting. My own opinion is that a few more months publication time would have been well worth the improvement in scientific quality that peer-review would have contributed.

The 29 papers cover theory, physical modelling, methods of measuring strains and rotations using geodetic, seismotectonic and palaeomagnetic techniques, and the results of measurements in various parts of the world. Several papers include basic mathematical descriptions of deformation and flow, and these lead into discussions of the way displacements on systematic sets of faults can be combined with rotations to achieve a given bulk deformation. Many of the problems of flow partitioning touched on here will be familiar to structural geologists concerned with crystallographic fabric development or the rotation of porphyroblasts, for example. The most elaborate of these kinematic models, that of Jackson & McKenzie, is intriguing, but is only valid for a unique orientation of the faults and an infinitesimal deformation. The reason is summed up by von Mises criterion: a general finite strain can only be achieved by slip on a minimum of five independent systems. This also invalidates in principle the analyses by Nur *et al.* and Garfunkel, who try to predict the rotations resulting from slip on one or two discrete sets of faults, and neglect the additional components of deformation required within the fault blocks to maintain continuity. Whether the predictions of these models have any significance can only be determined empirically: rotations (in Israel and in the Mojave desert) in the opposite sense to the bulk sense of shear, suggest that in fact they may.

A number of papers attempt to integrate various combinations of palaeomagnetic, seismotectonic, geodetic and structural data from specific areas: some of these, particularly from New Zealand and California, are very successful. Also interesting are those that deal with metamorphic or igneous terrains, such as the Pyrenean basement (McClelland & McCaig) and the Troodos ophiolite (Allerton), where there is no bedding to give an immediate indication of the palaeohorizontal. In these cases the analysis has to be in terms of the total rotational history of the rocks. A common problem with palaeomagnetic work is that the component of rotation about a horizontal axis is treated as an incidental feature that has to be 'corrected' before the component about the vertical axis can be determined, and the amount of tilt is commonly not even included in the published results. This can be very misleading: regional tilts are interesting and important; and the rotations determined by the traditional approach may not reflect what actually occurred. To take an extreme example, a rock body could be tilted about a horizontal axis quite different from its present strike, and then rotated about an oblique axis, normal to the inclined palaeohorizontal (e.g. bedding). The tectonic significance of this sequence of events would be quite different from that of the rotation about a vertical axis that a traditional palaeomagnetist might determine.

One potentially important result from a crystalline terrain was that of Dagley & Piper, from a metamorphic core complex in the Basin and Range province. They tentatively interpret their data in terms of a 30° tilt of the complex during exhumation. If correct, this implies that the presently gently-inclined detachment fault above the complex was originally much steeper. The authors appear not to have realized that this could be crucial evidence against the 'Wernicke model' for these faults, which they enthusiastically espouse in the paper.

A surprising and disappointing aspect of several papers is the analysis of fault-slip data in terms of palaeostresses. As Choukroune's paper in this volume points out, faults reflect finite displacements and should be analysed in terms of strain and rotation. One of the main reasons for the lack of a direct relationship between displacements and stress is that the material may rotate during deformation: in a conference devoted to the determination of rotations, it seems ironic that several participants were unaware of this elementary point.

The book contains many stimulating, provocative and informative papers. It is only a pity that they were not reviewed and selected more carefully.

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A third helping of crust

Condie, K. C. 1989. *Plate Tectonics and Crustal Evolution* (third edition). Pergamon Press, Oxford. 476 pp. Price £55.50, $100.00 (hardback); £30.00, $49.50 (softback).

Earth is probably the only terrestrial planet, in this solar system, that possesses a continental crust. Though the others have *some* kind of crust, Earth again appears unique in having active plate tectonic processes. This book presents the major models for the origin and evolution of Earth's unique crust. Since that crust owes much of its character to plate tectonics, the two subjects are, quite rightly, brought together—a far more useful and instructive approach than separate treatment.

The author has written this book with advanced undergraduate and postgraduate students in mind, and assumes that the reader has a basic grounding in geology, chemistry and physics. He hopes that it may also find use as a reference work. The subject matter is drawn from the fields of geochemistry, structural geology and tectonics, geophysics, oceanography and petrology; it covers the evolution of the crust over the past 3.8 Ga. This third edition represents a rewriting of more than 75% of the text of the second. Numerous figures have been added and the appended tectonic map of the world has been updated. There are new sections on meteorites, seismic tomography, mantle convection, acretionary terranes, mantle magma sources and their evolution, continental growth, secular changes in Earth environments, and Venus, as well as a completely new chapter on exogenic Earth systems. To all intents and purposes it is a new book that attempts to present the most up-to-date views on the various subjects covered.

A vast range of subject matter is dealt with. The text is clearly written in a style that betrays the origin of the material (a course of lectures given by the author). The punctuation, spelling and sentence construction are distinctly American. The numerous figures are properly referred to as illustrative of the textual material. However, many have been borrowed from other publications, and a significant proportion of these would have benefited from redrafting. Despite this, the printing is generally sharp and clean. The paper used is smooth, white and relatively thin, though not distractingly transparent. I examined only the softback edition, presumably aimed at the student market, and cannot say whether any of these properties are functions of cover stiffness. One major annoyance is the liberal sprinkling of misprints, the most embarrassing being the misspelling of "magma" in the publisher's blurb on the back cover. The map also contains at least one typographical error, in relation to the type of crust to be found on Greenland. Each chapter is concluded with a number of very useful summary statements and sound suggestions for further reading. The latter are drawn from books rather than research papers— a particularly good way of directing the interested reader to a broad range of opinion. Significant research papers are copiously referred to, and it is pleasing to see many of 1987–1988, and even a few of 1989, vintage. A brief summary of chapter contents follows.

Chapter 1 is a general introduction and survey of the sources of data which form the bases of several theories on the formation and evolution of Earth's crust. Plate tectonics is, of course, the assumed foundation of all theories.

Chapter 2 deals with the origin of the Earth–Moon system, and covers the types of evidence and the various models. Homogeneous accretion models are favoured in a partisan manner. The author leans toward the giant impactor model for the origin of the Moon, selectively ignoring the same isotopic difficulties he cites as evidence against capture models.

Chapter 3, on the structure, composition and evolution of the mantle and core, deals with mantle heterogeneities, mantle convection and the causes of seismic discontinuities. It is soundly commented that progress in discovering the sizes, shapes and distribution of different mantle reservoirs will come through advances in seismic imaging (an opinion guaranteed to annoy some geochemists).

In Chapter 4 comes the 'nitty-gritty' of the book—the crust. The various types of crust are introduced and their geophysical properties quantified. There is an over-simplistic section on metamorphism. The composition of the crust and its subdivision into provinces are discussed. There is much here with which the opinionated reader may take umbrage.

Plate tectonics is introduced in Chapter 5, and its geomagnetic and seismic bases are examined. There are sections on the kinds of plate boundaries, relative plate motions and their consequences, and on sundry other topics. Expression is occasionally clumsy but the substance cannot be faulted, within the ambit of the theory.

Tectonic settings are carefully dealt with in Chapter 6, each setting being discussed according to its characteristic lithological associations, metamorphic style and mineral and energy deposits. All readers (and especially terrane accretionists) should heed the author's admonition to great caution in correlating ancient lithological associations with present-day tectonic settings. This chapter contains numerous diagrams, culled from Scholl *et al.* (*Geology* **8**, 564–568, 1980), which I did not find instructive.

Chapter 7, on magma associations and *mantle* sources, covers the kinds of magmas produced in each of the major tectonic settings, and clearly demonstrates that the seed sown by Australian workers (over the past 15 years) has fallen mostly on stony ground. The sections of mafic rocks are competent summaries of current opinion. Granitoid rocks are dealt with perfunctorily, perpetuating the common but false impressions that 'S-type' granitoids are syncollisional muscovite leucogranites, and that 'I-types' are formed through fractional crystallization of mantle-derived mafic magmas. The intraplate associations of several different types of granitoid suites are virtually ignored.

Chapters 8 and 9 cover Phanerozoic orogenic systems and Precambrian crustal provinces, respectively. Differing styles of crustal evolution are soundly discussed, with reference to various case studies, within the established plate tectonic framework. In Chapter 8 the author resists the temptation to extend the North American terrane accretion model to all other continents. In many minds, this model remains 'suspect' and has completely failed to produce any advance in understanding the evolution of some regions (e.g. SE Australia). The problem may lie in the existence (and non-recognition) of fundamental differences in the palaeogeographic positions, of SE Australia and western North America, relative to the other continents. Models for the formation of the Archaean crust are reviewed in Chapter 9. The tectonic context of this ancient crust is assessed (the warning in Chapter 6 notwithstanding) and it is concluded that plate tectonics has operated since the early Archaean. In this chapter there is also an uncritical regurgitation of the largely discredited CO_2-flushing theory for the origin of granulite terranes.

In the final two chapters, the book turns again to discussion of Earth as an integrated system. Chapter 10 is on the origin and evolution of the crust and mantle. It takes up where Chapter 2 ends and actually deals with the origin, evolution, composition and growth rates of the continental crust, and the origin of plate tectonics. Here the author finally succumbs to accretionary temptation. On page 346 he states that "It would appear that collision of arcs and microcontinents is the most important mechanism by which continents have grown". This occurs in the same paragraph where the processes of over- and underplating are accorded brief mention as possible growth mechanisms. Would it be nit-picking to point out that no new crust is created in accretion—only redistributed? Perhaps we should distinguish between mere areal expansion of a chosen continent and true growth in total continental volume. This chapter also contains an interesting section on the comparative evolution of the known terrestrial planets. However, it does not really deal with what is probably the main reason for the unique development of a stable continental crust on Earth ("No water, no granites—no oceans, no continents."; Campbell & Taylor, *Geophys. Res. Lett.* **10**, 1061–1064, 1983).

Chapter 11 (exogenic Earth systems) deals with the atmosphere, hydrosphere and biosphere, and their interactions with each other, the crust and the mantle. The chemical evolution and structure of Earth's atmosphere and oceans are compared with the situations on Venus and Mars. Climate and sea-level changes are treated, and there is a section on the origin of life. Evolution and plate tectonics are discussed, stressing the effects of plate movements on the creation and destruction of ecological niches. The causes and immediate mechanisms of extinction are discussed; as causes, cometary impact is favoured and volcanism dismissed.

To summarize, this is a worthwhile compilation of current collective wisdom (and lack thereof). There is something here for everyone in the Earth sciences, and every institutional geological library should possess at least one reference copy. Many specialists will want a personal copy. As for the student market, I fear that undergraduates may not buy it, postgraduate students in the U.K. might purchase a copy if they feel wealthy, while their opposite numbers in the U.S.A. may be financially more able to cope with the expenditure. In any case, all should take a look at this book, to see where their bit of research might fit into (and perhaps alter) the global picture.

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Maps divide and rule

Maling, D. H. 1989. *Measurements From Maps—Principles and Methods of Cartometry*. Pergamon Press, Oxford. 577 pp. Price £45, $80 (hardback); £20, $36 (softback).

This book is concerned with cartometry—"the measurement and calculation of numerical values from maps". We all use maps at some time or other and as structural geologists are often interested in making measurements from them. From this point of view I approached the book, first turning to the cover. "Maps and Measurement" it says on the front, over a grey/white image of the eastern Mediterranean. On the back it is suggested that cartometry can be extended to satellite images, air photographs and photomicrographs; it all sounds wonderful. The definition of maritime boundaries as established by the UN Convention on the Law of the Sea, frankly, was not a big selling point with me, but this was offset somewhat by a further sentence implying the inclusion of stereological methods. Well I knew this was just the publishers sales pitch, better read the book and find out what it's all about.

On page 1 we find that the basic techniques of cartometry involve the measurement of distance, area and direction, together with the counting of objects on a map. Well I have used a ruler and can count to 10 on a good day, and direction measurement sounds particularly relevant to structural geology. Unfortunately, the latter is covered in little detail and mainly from the point of view of navigation and the Mercator projection.

Next, a little on maps themselves. "The scale of a map is its most important mathematical property"; profound as this may be I was tempted to add the word "discuss" to produce a typical high-school exam question in geography. Then it is on to measuring distance and area. Here we are told how to use a ruler and dividers, and that one can estimate the area of some feature on a map by cutting it out and weighing it. Given the price of maps today, and the level of recurrent grant to university departments, I would not recommend proposing this for first year practicals to your department head! Right at the end of the chapter on area measurement, there is a brief mention of image analysis; I remember the "Quantimet" and even when it was state of the art. By now I was realizing that modern (dare I say computerized) ditigal methods are not featured too highly in this book. But on we go, with chapters on measurement errors, statistical sampling and accuracy, which contain many interesting points, although little to stimulate the reader. I particularly liked the idea that "*personal errors* include mistakes . . . in manipulating the dividers"; in the right (or wrong) hands a pair of dividers could indeed be stimulating!

Now the title of Chapter 10, "Deformations of the Medium", is