



**Geological Society of America  
Structural Geology & Tectonics Division**

**2007  
Best Paper Award  
Presented to Dave Pollard and Ray Fletcher**

Pollard, D.D. & Fletcher, R.C (2006) *Fundamentals of Structural Geology*. New York, Cambridge University Press. 512 p.

*Citation by Peter Geiser*

I have been given the honor of presenting the 2007 Division of Structural Geology and Tectonics best paper award to Dave Pollard and Ray Fletcher for their text "The Fundamentals of Structural Geology. I also feel that this is a bit like being given the honor of being between a rock and a hard-place as our community seems to be in the midst of what I'd like to think of as a constructive tension. A tension between those whose work and teaching emphasizes geometry and kinematics, to which group I confess to belong, and those, such as Dave and Ray, advocating a greater emphasis on mechanics.

From an historical perspective, Structural Geology is no different than any other natural science, moving from an initial descriptive phase full of classifications and nomenclature towards a more quantitative manifestation and the working out of first principals. As with all things human there's always a bit of rancor that attends this process. In fact Dave and Ray citing the eminence grise Bruno Sander who proposed that "we set aside much of the physics in our initial study of rock deformation and focus exclusively on kinematics", then go on to note that although a prominent school of structural geologists continue to follow this approach, they, Dave and Ray, are not members of this academy.

Of course a lot of this has to do with how much math and physics you've had and how comfortable you are with these tools. The problem with math and physics is that they are so abstract!. And as Samuel Johnson chose to demonstrate, what's more real than a rock? Also many of us derive great pleasure in working out the often intricate geometric puzzles that describe the history and physical appearance of our beautiful planet that moves in such mysterious ways.

Yet as I think we will all admit, the descriptive phase even in its more quantitative manifestations takes us only so far. And after all, science is fundamentally about first principals, the How, rather than the "what is it?"

If you will indulge me, I would like to describe my own moment of epiphany about first principals, where, like Lawrence Fehrlinghetti I encountered that penny candy store beneath the El, the place where I first fell in love with unreality and a girl ran in and her hair was rainy and a voice said "too soon, too soon".

So far, far away and a long time ago (1961) I was serving as a field assistant to a U Mass graduate student, John Pepper. There we were in deepest, darkest New Mexico attempting to map the apparent chaos of the Tinnie fold belt, where the San Andres Limestone detaches on the Yeso formation forming an incredible tangle of rock. On the day of epiphany John and I were

slowly mapping our way up one of the nameless arroyos that dissect the area. Suddenly, like the opening of a theater curtain, our arroyo widened into what seemed like a giant amphitheater at the head of which was cliff perhaps 50 to 100 meters high displaying a structure that made us gasp in disbelief. Massive limestone beds on the order of 5 m thick were folded like toothpaste forming vertical isoclinal folds the height of the cliff. Neither of us had ever seen nor read of such fabulous creatures, how could such things be? How could rocks, which at most saw 100o C, act like toothpaste? It seemed impossible yet there it was. The description, the "What", was clear. The "How" was a total mystery, a seeming physical impossibility which we could not explain.

So I think we're all on the same page with regard to what constitute the truly fundamental and in some ways, the most interesting questions of our science; the How question, that of the so-called "first principals"" as described by physics and its attendant mathematics. The problem is that structural geology has lacked a formal pathway into this arena.

To me such pathways have two major properties. First the discipline itself is taught in terms of the Math and Physics that describe it, i.e. as an integral part of the subject, not a passing reference. Secondly it is begun at the undergraduate level, because that's where you have to start. Take the abstract and make it real, the sooner the better.

So where does this leave Structure? I feel that up to now there has been only one text that truly advanced the use of mathematics in structure and that is Ramsay's "Folding and Fracturing of Rock". To my mind what makes Ramsay's contribution seminal is the clarity and depth of the integration of the mathematics with real rocks and with its immediate application to field problems. Instead of having random equations appearing out of nowhere, Ramsay develops the equations before your very eyes.

Dave and Ray take this approach several steps further, starting with elementary field techniques and relatively elementary mathematics, they proceed through virtually the full scope of structural geology, developing the requisite math and physics en route. And they really do develop it. Not only do they write with clarity, you can actually learn mathematics and physics from their text, but like Ramsay they make explicit the relationship between the abstraction of the math and physics and the real world of structural geology.

I'd like to close by returning to the earlier Sander citation. It's worth noting that not only is it highly recursive, Dave and Ray citing Sander citing Becker citing none other than Lord Kelvin, so in the end the proponent of the study of kinematics turns out to be a very eminent physicist. Further, in this very same quote Kelvin goes on to say that kinematics, although important, is only "to be considered as a first step". The implied second step being the working out of first principals through mechanics. Thus there is a spirit of harmony in the Kelvin quote with respect to kinematics and mechanics; to understand physical phenomena you must first be able to describe them.

Well perhaps it's time for Structural Geology to take that second step towards first principals more seriously, perhaps making it an integral part of its discipline, perhaps moving towards making it its very basis. I would like to suggest that with the advent of Pollard and Fletcher's

text, structural geology now has a tool for making such a project a reality and it is for this reason that it is my great pleasure to present them with the Division's best paper award for 2007.

#### *Response by Dave Pollard and Ray Fletcher*

David Pollard would like to acknowledge several teachers and colleagues who shaped my understanding of structural geology as presented in the textbook. Donald McIntyre of Pomona College sparked my interest in the subject and provided a wonderful historical context. Arvid Johnson of Stanford University introduced me to mechanics integrated with detailed field mapping. John Ramsay of Imperial College showed me how to unravel the geometry of complex structures in metamorphic terrains and use kinematic indicators to measure strain. Neville Price of Imperial College help set my research focus on brittle deformation, a topic that continues to challenge and fascinate me to this day. Atilla Aydin of Stanford University continues to provide an insightful perspective on structural relations in the field and the applications of structural geology to the energy industry through the Stanford Rock Fracture Project. Ray Fletcher, communicating largely through countless emails as we worked on this project, demanded a level of scientific integrity and physical accountability that set the tone of the entire book. This textbook would not have been possible without the help of more than 50 graduate students, who can not be named individually here, but are gratefully acknowledged. They provided insightful feedback, worked problem sets, participated in thoughtful discussions, and most importantly carried out the basic research that underlies much of material presented in the book.

Ray Fletcher also would like to acknowledge several teachers & colleagues. Bill Brace's course initiated my interest in structural geology. The C I got provided a well-appreciated expert opinion on how far I needed to go to become competent. Bill later showed me the results of indentation of an unconfined sample meant to achieve high pressures under the indenter and hence ductile deformation. It occurred to me that it would be interesting to devise a mathematical model of such an inhomogeneously deforming body. Imagining the indenter to be a body of magma pushing upward against the country rock suggested a model for emplacement of an igneous stock. Simplified to achieve tractability, the igneous stock morphed into a mantled gneiss dome. From Emir T. Onat's course, I learned enough continuum mechanics to carry out a thesis project on this topic. Field motivation was provided by John Rosenfeld, master of rolled garnets and New England gneiss domes.

Bill Chapple supplied uncounted hours of scientific discussion over the course of my graduate study and beyond. In a reading course, he asked me to find the error in Ode's classic paper on the dike pattern around the Spanish Peaks, an error later corrected to good effect by Otto Muller & Dave Pollard in 1977. Chapple had to tell me what it was: violation of a boundary condition. After giving my first AGU talk, I discovered that I had made the same mistake! Hopefully, our textbook provides some problems and avenues for research that are sufficiently challenging to cause the reader to make errors

- great sources of insight! I also thank my few but exceptional graduate students, all of whom mapped structures, and formulated neat models for how they might have formed. Al Hofmann, Bernard Hallet, Arvid Johnson, Dave Pollard, Enrique Merino, and Sue Brantley have been valued collaborators in efforts that showed, in some cases, that a complete mechanics could be applied to many, if not all, geological processes.

We would like to thank the officers of the SG&T Division for their efforts to promote structural geology and tectonic within the GSA, and the members of the Award Committee for their choice of our book as this years best paper.

Pete Geiser deserves a special word of thanks for his citation which accurately identifies the central role in our textbook of the question: "How did this deformation come about?" He also cites our attempt to "make explicit the relationship between the abstraction of the math and physics and the real world of structural geology." We worked hard on that, continuing efforts by numerous workers, some mentioned above, that go back at least 50 years. Compelling examples linking field observations to results of a complete mechanical analysis are not that easy to find. However, a working knowledge of a complete mechanics invariably provides insight on deformation processes from field observations, and is something that can be easily carried into the field.

None-the-less there are tangible indications that our discipline is, in Pete's words, taking the second step, perhaps for the 2nd, 3rd, or nth time. For example, there is the Special Session at this meeting organized by Dave Wiltschko and John Spang on "Bridging the Gap Between Kinematics and Mechanics." Clearly these structural geologists are contributing to the effort to integrate geometry and kinematics with constitutive laws and the equations of motion.

Speaking of those equations... they are exactly what is necessary to address the spatial and temporal variations in the kinematic quantities such as displacement and velocity, strain and deformation rate, that we love to talk about at the outcrop. Fundamentals of Structural Geology provides a new framework for the investigation of geological structures by integrating field mapping and mechanical analysis. It emphasizes the observational data, modern mapping technology, principles of continuum mechanics, and the mathematical and computational skills necessary to quantitatively map, describe, model, and explain deformation in Earth's lithosphere.

Structural geology is a rapidly evolving discipline which is transforming as all science disciplines do from qualitative, descriptive, and taxonomic to quantitative, model oriented, and process focused. We hope that students, young and old, will find our textbook a helpful guide to this transformation.