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BOOK REVIEWS

Fold and thrust belts—in tribute to Dave Elliott

Mitra, S. and Fisher, G. W. (editors) 1992. *Structural Geology of Fold and Thrust Belts.* The Johns Hopkins Studies in Earth and Space Sciences, The Johns Hopkins University Press, Baltimore, Maryland, U.S.A. 254 pp. (ISBN 0-8018-4350-2) Price $55.00 (hardback).

This volume is a fitting tribute to David Elliott.

Dave Elliott was a driving force behind the renaissance of the late 1970s and the 1980s, in the elucidation of the nature and significance of fold and thrust belts. In the short period between 1976 (when he published *The Motion of Thrust Sheets*) and his death in 1982 he changed the way we think about the geometry and kinematics of fold and thrust belts, about deformation mechanics and mechanisms in fold and thrust belts, and about regional structural styles of fold and thrust belts. Therefore, it is appropriate that these three themes should define the three sections into which the chapters in this volume are grouped. Dave had an uncanny talent for integrating elegant geophysical and geochemical theory with perceptive field and laboratory observations, and accordingly it is fitting that this integration between theory and experiment should be an over-arching motif among the three sections in the book. Dave's profound influence on the elucidation of fold and thrust belts can be associated with the many very capable and enthusiastic research students who came to work with him, and to his numerous lectures and his frequent field and laboratory visits with many colleagues in North America and western Europe, as well as with the several key papers that he published. Most of the chapters in this volume were written by those former students and colleagues who knew him as "an enthusiastic and pioneering student of fold and thrust belt structure".

Part I of the volume, which deals with "Geometry and Mechanics", consists of four Chapters. D. A. Medwedeff has urged extensive borehole data from petroleum exploration, together with data from surface exposures of the Wheeler Ridge anticline, in the Transverse Ranges of California, to document the configuration of an active, laterally propagating, 'blind' thrust wedge; and also to show how the stratigraphy and structure of sediments that were deposited during the folding that is related to the faulting can be used to constrain interpretations of the kinematics of the structure. R. W. H. Butler has developed kinematic models that link variation in concurrent thrusting and folding between and along different structural levels. He has used these models to explain structural relationships at the southwest 'termination' of the Morcles nappe, in the Alps, near the Swiss–French border. D. G. De Paor has used temporal maps (horizontal distance–time projections along structural cross-sections) to illustrate the evolving relationships among thrust faults, folds, erosion and sedimentation in the foreland of the Spanish Pyrenees. S. Mitra has reviewed and critically evaluated techniques for the construction of balanced cross-sections, using examples of sections from the Appalachians, Taurus Mountains, and Papua-New Guinea.

Part II comprises six chapters dealing with "Mechanics and Mechanisms". P. J. Hudleston, following up on an idea developed by David Elliott, has outlined similarities and differences between the motion of glaciers and the evolution of fold and thrust belts. S. Wojtal, also following up on an idea developed by David Elliott, has used an analytical model, derived from analyses of glacier flow, to explain the nature of mesoscopic minor faults and variations in their frequency with distance above the sole fault of the Cumberland Plateau thrust sheet of the southern Appalachians. M. P. Coward, P. A. R. Nell and J. Talbot have extended previous work on deformed worm tubes in the Cambrian Pipe Rock from the Moine thrust zone in the Assynt district by analyzing in detail the bedding-parallel longitudinal and shear strains in four different areas of folding associated with thrusting. G. Mitra has reviewed the microstructures and deformational histories of quartzofeldspathic crystalline basement rocks for a range of environments covering the transition from cataclastic to quasi-plastic deformation, using, as illustrations, examples from the Wind River Mountains of Wyoming, and the Blue Ridge Mountains of the southern Appalachians. J. A. Gilotti has investigated the applicability of the concept of a rheologically critical matrix percentage to the elucidation of the development of the arkosic mylonites along the Särv thrust in the Swedish Caledonides. S. E. Boyer has used geometric relationships between thrusts and deformational fabrics within and around the Grandfather Mountain window in the Blue Ridge thrust sheet to outline a complex and protracted history of development and reactivation of thrust faults in this part of the southern Appalachians.

Part III of the volume deals with "Regional Structural Styles" and consists of four chapters. N. B. Woodward has analyzed variations in structural style of part of the Idaho–Wyoming thrust belt in terms of the concept of structural lithic units, and of the initial stratigraphic controls on the rheological heterogeneity and anisotropy of the rock mass. E. W. Mountjoy has documented the unusual occurrence of numerous back-rotated, southwest overfolds and thrust faults in the southern Canadian Rockies near Jasper, Alberta, and he has shown how these back-rotated structures can be attributed to progressive rotations due to displacements on a sequence of underlying listric thrust faults. R. Deschene and E. W. Mountjoy have outline a new interpretation of the regional structure of the Canadian Rocky Mountain Main Ranges in the Jasper–Yellowhead structural culmination. This involves later, 'out-of-sequence', steep, "post-metamorphic" folds and faults that deform earlier low-angle thrust faults and folds which were active "during the peak of metamorphism". D. Anastasio has used a combination of structural data and the stratigraphic record of synorogenic foreland basin sedimentation to outline the structural evolution of the external Sierra of the southern Pyrenees of Spain, and the relationships between contemporaneous thrusting and transverse, halotectonic folding.

The book is well prepared. The arrangement of the chapters is logical and coherent. The format is attractive, and there are few typographical errors. The reproduction of photographs and photomicrographs is good, and most of them are very informative. Unfortunately, the quality of the figures varies from chapter to chapter, and in a few chapters the scale of the lettering and of the lines has been reduced to the point where they are so small and thin as to be barely legible.

This book is a significant addition to the literature of structural geology. It brings together a diverse body of important information on the structural geology of fold and thrust belts. Some of this information comprises new observations and ideas, but most consists of useful summaries of recent advances in the understanding of fold and thrust belts. Those interested in the structural geology of fold and thrust belt will find this volume well worth reading, and not too expensive to own!

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Bering shelf strike-slip basins

Worrall, D. M. 1991. *Tectonic History of the Bering Sea and the Evolution of Tertiary Strike-slip Basins of the Bering Shelf.* Geological Society of America Special Paper 257. 120 pp. + 3 sheets in a pocket. Price $42.50 (softback).

This beautifully illustrated book (72 pages of figures out of a total of 120 pages; eight full-page figures in color) consists of two parts, each of which can be read separately without its companion, as the author himself suggests. The first part gives an overview of the geology and tectonic history of eastern Siberia, the Bering Sea and Alaska, and the second discusses in detail the geometry and origin of the Tertiary basins on the Bering shelf. Both parts are extremely useful, particularly for geologists working in the area, because the book includes a compilation map of the entire area (inclusive of eastern Siberia), very well-presented descriptions of the geology of the area, and a wealth of previously unpublished, confidential industry data of the Bering shelf basins. For geologists working in other areas, the book is important, particularly because of the new insights in the geometry, origin and development of strike-slip basins.

In the first part of the book (pp. 7–33), Worrall discusses the geology and tectonic history of the area. He divides the area into six regions, which are roughly from north to south: I, North Slope block (northern Alaska and northeast coast of Siberia); III, South Anyuy-Brooks suture; II, East Siberian block; IV, Okhotsk-Chukotsk-Beringian-Chugach active margin; V, Olyntorsky–Bowers volcanic arc; and, VI, Kurile-Kamchatka-Aleutian volcanic arc.

Region I (North Slopes of Alaska and eastern Siberia) consists of Precambrian basement overlain by Paleozoic carbonate and clastic rocks. Its southern margin was a passive one. It drifted southward and collided with Region II during the late Jurassic and early Neocomian.

Region II consists of the Siberian Precambrian craton with its Paleozoic–Mesozoic cover in the west, and, in the east, at least two cratonic microcontinental blocks which, during Carboniferous to late Jurassic time, collided with and were attached to the Siberian continental plate due to E–W plate convergence. The southern boundary of the East Siberian block is the S-facing Uda-Murgal volcanic arc which was active from Permian to late Jurassic time.

Region III, lying between Regions I and II consists of ophiolites and Neocomian arc volcanic and related sedimentary rocks. They were emplaced northward across the earlier passive margin of the North Slope.

Also during the Neocomian, the S-facing Region IV volcanic arc formed, south of Regions I, II and III, as a result of the northward subduction of the Kula plate. At the same time, a NE-facing volcanic arc (Region V) developed somewhere to the south in the western Pacific. The original location of the arc and the reason why it formed are unknown. The latter arc collided with the East Siberian block in the late Paleocene and subduction jumped from Region IV southward resulting in the formation of the S-facing Aleutian arc (Region VI); most of the Bering sea is underlain by older Kula-plate oceanic lithosphere, captured in the back-arc basin when the subduction zone jumped southward.

Worrall has performed, in my opinion, an outstanding job in describing the geology and the tectonic history of the area, and presenting the compilation map (plate 1). The descriptions are so clear, that—even without previous knowledge of the area—one can construct alternative tectonic scenarios, if one does not like the one presented by Worrall. As a reviewer, I feel obliged, however, to point out some apparent conflicting statements and oversights.

First, in one place (p. 10) the Uda-Murgal volcanic arc and trench (southern margin of Region II, the East Siberian block) is described as of "late Jurassic and earlier age" (Permian to middle Jurassic flysch and basaltic andesites are mentioned), but in the synthesis chapter (p. 20), Worrall says that it is a late Neocomian structure. The latter interpretation is straightforward: the Uda-Murgal is part of Region IV (Okhotsk-Chukotsk-Beringian-Chugach volcanic arc). However, if the first description is correct (and the compilation map seems to indicate that), the explanation for the formation of the Uda-Murgal is much more complicated, because the Permian to late Jurassic amalgamation of the East Siberian block (E–W contraction) is contemporaneous with the activity of the Uda-Murgal arc (N–S contraction). This may indicate that the two microcontinental blocks of the East Siberian region were displaced as forearc plus backarc slivers due to displacement partitioning in a setting of oblique plate convergence; E–W compression may then be the result of the curved nature (convex toward the continent) of the arc.

Correctly, I believe, Worrall called upon oblique convergence, somewhat similar to the one discussed above, for the emplacement of the Talkeetna superterrane (Wrangellia, Peninsular and Alexander terranes) to Region IV (see map on plate 1 and fig. 15 on pp. 24 and 25). Unfortunately, the cross-sections through southern Alaska in fig. 13 (p. 21) are not consistent with the tectonic model of fig. 15.

Another problem with Worrall's model for Alaska is that late Cretaceous and Cenozoic N–S contraction in the Brooks Range is not accounted for in the cross-sections of fig. 13.

The second part of the book is divided into two sections, one dealing with the Tertiary basins (Anadyr, Navarin, St. George and North Aleutian basins) situated on the accretionary complex of the Beringian margin (Region IV), and the other dealing with the Tertiary Norton basin which lies behind the old Beringian arc–trench complex. This Tertiary basins section is richly illustrated particularly with a large number of seismic reflection lines. The conclusions are mainly based on these seismic data, but also on two drill cores.

The Beringian margin ceased to be an active subduction zone in the early Eocene, when subduction jumped to the south and formed the Aleutian volcanic arc. Deformation, however, continued in the Beringian margin. Campanian to upper Middle Eocene forearc basin deposits were folded, faulted, uplifted and locally eroded, prior to the deposition of lower Upper Eocene sedimentary rocks which are the earliest deposits in the new Tertiary basins of the Beringian margin. The trend of the fold axes is about 30° more westerly than the trend of the Beringian margin; the folds occur often in right-stepping, en échelon trains. Major en échelon faults parallel to the margin are interpreted as right-lateral strike-slip faults; minor N–S-striking faults are normal faults. Rapid subsidence (up to 0.5 mm year^{-1}) of the basins started in the early Late Eocene and continued until the Late Oligocene after which the subsidence rates decreased (to about 0.03 mm year^{-1}). Sedimentation rates during the Oligocene were much smaller than the subsidence rates; organic-rich sediments were deposited only in the deepest part of the basins. Subsequently, shelf-type sediments were deposited across the entire region. During the Oligocene to Pliocene, folding was minor, but the dextral strike-slip faults became major through-going structures.

The geometry and evolution of the Tertiary basins along the Beringian margin has been documented very well by Worrall in a series of isopach maps and cross-sections. Although the basins are clearly the result of strike-slip displacements along the old Beringian margin, the geometry of the basins is very different from the pull-apart model in which the boundaries of the basins are major normal faults. Although normal faults occur in the region, they are of minor importance and little displacement has occurred along them. Worrall shows convincingly that basins are the result of down-warping and not of normal faulting. However, Worrall still attributes the origin of the basins to wrench tectonics, citing Rodgers (1980) who performed a series of experiments using an elastic dislocation model. The patterns that Rodgers obtained are quite comparable to the geometries of the Beringian basins. Worrall compared these basins with other examples in the literature (e.g. Cariaco and Vienna basins); it appears that the Beringian-type basins may be far more common than the classical pull-apart basins.

The evolution of the Tertiary Norton basin is, according to Worrall, not much different from that of the Tertiary Beringian margin basins, but instead of being related to the Bering shelf margin, it is supposedly related to the NE–trending, right-lateral Kaltag fault in Central Alaska.

The second part of the book dealing with the evolution of the Tertiary strike-slip basins, it very well written and exceptionally well documented. A few minor comments can be made, though. First, it is somewhat confusing to have some figures occurring in the text, some at the end of the text, and others on separate sheets in the pocket; it takes some searching to find them. Secondly, Worrall's model for the origin of the Tertiary basins is based on elastic material properties; isn't it time to explore models with non-elastic material properties? Thirdly, all seismic lines shown in the book, are interpreted lines; as Worrall's interpretations of seismic lines of the Norton basin are substantially different from those of Fisher *et al.* (1982), it would have been worthwhile to see the uninterpreted lines next to the interpreted ones. Fourthly, I would have liked Worrall to speculate on how the strike-slip faults and the down-bulge propagate downward beyond the deepest seismic reflection data and how these structures are related to Pacific–North American plate interaction; are the strike-slip faults merging into a common low-angle detachment surface which connects with the Aleutian subduction zone?

In summary, my comments and criticisms do not change my belief that this is an excellent book. It deals primarily with strike-slip basins in the Bering Sea and on the basis of a large number of seismic lines a new model for such basins has been proposed. Never have I seen a paper or a book with such unique documentation. Every geologist interested in basin evolution and every geologist working in and around the Bering Sea should have access to this book.

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