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Preface

This Special Issue consists of 23 papers on the geometry, kinematics, and dynamics of fault-related folding. The issue is an out-growth of the Penrose conference on fault-related folding (Anastasio *et al.*, 1996) that was held at Banff, Alberta in August 1995. The conference, which was supported by contributions from the Geological Society of America, the National Science Foundation (U.S.A.), and a number of United States and Canadian petroleum companies brought together 82 participants from academic institutions, consulting firms, and energy companies within the United States, Canada, New Zealand, France, Spain, Great Britain, Germany and Switzerland. Subsequently, a general call for papers for a special issue on the topic appeared in the *Journal of Structural Geology*, and 33 papers were submitted by authors from around the world.

The widespread interest in fault-related folding represented by this special issue stems from the explosive growth in fault-related fold modeling over the last 15 years. The promise of quantified fault-related folding, and its immediate and important applications to problems ranging from hydrocarbon exploitation to seismic hazards, has attracted both the enthusiasm of many geoscientists and the variety of approaches sampled by this issue. Current research as represented by this special issue focuses on testing kinematic hypotheses and extending them into new dimensions of space, time and stress. The first papers re-visit the geometry of fault-related folds from field and theoretical perspectives, exploring their kinematic inferences and testing validity of existing kinematic hypotheses. The latter papers extend current kinematic models by (1) reconstructing time through analysis of incremental and finite strain, mesoscopic structures, growth strata or analog modeling, (2) adding an additional spatial dimension, or (3) constructing dynamic models integrating stress and material properties.

The first papers consider some of the geometric aspects of fault-related folding. Marrett and Bentham use a geometric model for fault propagation and folding (Chester and Chester, 1990) to devise a technique by which geological and geophysical data defining fold form can be used to produce a balanced cross-section that predicts fault trajectory and slip. Hedlund considers displacement–distance relationships predicted by simple fault-related fold models and concludes that the relationships can reflect factors other than the relative rates of fault slip and fault propagation. McConnell, Kattenhorn, and Benner show displacement–distance relationships for outcrop-scale fault-related folds which are consistent with growth of hanging-wall anticlines and footwall synclines during propagation both up and down dip from a nucleation point.

These papers are followed by a series of papers on the kinematics of fault-related folding. Contreras and Suter present two-dimensional models for duplexes and show that planar roof duplexes require forelimb thinning. Medwedeff and Suppe evaluate the implications of fault-bend fold theory for faults with multiple bends and show that generation and interference of axial surfaces can lead to complex and broadly curved fold shapes. Woodward presents a five-step kinematic model for the evolution of break-thrust folds. Models such as these provide the impetus for field studies that test the predictions of the models. Thorbjornsen and Dunne compare geometric and kinematic tests for the origin of fault-related folds in the U.S. Appalachians. They show that fold origin is most tightly constrained by kinematic tests involving micro- and mesostructural and finite strain distributions. Erslev and Mayborn use field and photogrammetric data to document the geometries of four fault-propagation folds from the Canadian thrust belt which developed by progressive limb rotation about fixed anticlinal hinges. They show that vertical and lateral changes in fold geometries indicate a complex interplay of multiple modes of folding. Homza and Wallace document the geometries and fabrics of complex detachment folds in the Brooks Range, Alaska, U.S.A. They present a model for fixed hinge detachment anticlines with variable detachment depth that explains the fold geometries better than conventional constant depth-to-detachment models. Finally, Anastasio, Fisher, Messina, and Holl use incremental strain histories to analyze large-scale décollement folding in the Lost River Range, Idaho, U.S.A. They show that folding occurred primarily by progressive layer spin but samples also record a varying component of internal rotation related to layer-parallel shear toward the pinned upper flat panel or the hinge of the Willow Creek anticline.

The next papers evaluate the kinematics of fault-related folding based on restoration of related growth strata. Poblet, McClay, Storti, and Muñoz characterize the predicted growth stratal geometries for décollement folds with variable limb dip-constant limb length, constant dip-variable limb length, and variable limb dip-variable limb length. Model results are applied to natural examples from the Spanish Pyrenees. The two following papers deal with Wheeler Ridge anticline, an active fault-related fold in California, U.S.A. Mueller and Suppe describe remarkably large and continuous stepped terraces and alluvial fan ridges on the front limb of the anticline, which they ascribe to periodic kink bend migration of the frontal limb during seismic slip on the underlying blind thrust. Mueller and Talling show that the ridge is segmented into three fold segments bounded by tear faults. They hypothesize that the lateral propagation of the anticline was episodic, with the fold growing through multiple earthquakes before stepping eastward to a new tear fault. The following paper by Ford, Williams, Artoni, Vérges and Hardy combines restorations of growth stratal geometries and forward modeling to characterize the three-dimensional kinematics and mechanisms of growth folding at Sant Llorenç de Morunys, Spanish Pyrenees. They conclude that folding is most consistent with a trishear fault propagation folding model involving non-rigid limb rotation. Suppe, Sabat, Muñoz, Poblet, Roca, and Verges use high resolution restorations to evaluate the final stages of deformation for the same structure and argue that the latest increments of fold growth were dominated by non-steady kink-band migration and sedimentation. Finally, Rowan describes the three-dimensional geometry of pre-growth and growth strata along the frontal fold of the Mississippi Fan fold belt in the Gulf of Mexico. Restorations are consistent with a three-stage evolution consisting of (1) initiation of detachment folds at buckling instabilities centered on salt pillows, (2) break-thrust folding in response to increased shortening rates, and (3) further fold amplification by rotation and uplift of the backlimb. In this example, the geometries of individual fold segments dictated the fault geometries.

The next three papers place fault-related folds in the larger context of thrust belt evolution. Meigs uses field relationships and magnetostratigraphy to identify three distinct deformation events along the emergent Spanish Pyrenean thrust front. Individual structures show evidence for folding followed by thrusting, and nearly every structure active during the first event was also active during the second, when most of the thrusting occurred. Mitra and Sussman present a model for connecting splay duplex formation that involves development of imbricates that connect with a pre-existing roof thrust. Connecting splay duplexes like the one they describe from the Canyon Range, Utah, U.S.A. can form in the interior of the mountain belt and provide a mechanism for the preservation of wedge taper. Tavarnelli uses cross-cutting relationships for mesoscale structures in the Apennines to show that the thrust belt shows evidence for layer-parallel shortening followed by folding and then thrusting.

The last four papers deal with the mechanics of fault-related folding. Wibberley evaluates cataclastic fault seams within the Glencoul thrust sheet in northwest Scotland and shows that cataclastic failure is restricted to portions of the thrust sheet that have moved over frontal bends with smaller radii of curvature. Using estimated slip rates allows for determination of the strain rates required for fracture failure. Strayer and Hudleston present a numerical model for fold initiation at ramps, with boundary conditions and rheology varied to generate fault-bend folds, fault-propagation folds, and wedge folds. The model treats rock layers as continua with elastic–plastic Mohr–Coulomb constitutive relations and leads to predictions for the distribution of incremental and finite strains as the structures evolve. Cooke and Pollard use numerical experiments to investigate frictional slip on bedding in the vicinity of dipping faults. In contrast to many kinematic models for fault-related folding, fault slip commonly induces symmetric folding in both hangingwall and footwall, with fault flats nucleating on bedding at ramp tips. The last paper by Storti, McClay, and Salvini models the nucleation and growth of fault-related folds using sandbox experiments. In these experiments, thrust-related anticlines grew progressively from initial layer-parallel shortening, to décollement folding, to thrust-tip folding, and eventually to thrust-ramp folding.

As one can see from the papers within this special issue, there is a diversity of approaches to the study of fault-related folds. These approaches are complimentary and in some cases, different approaches have led to similar conclusions. For example, numerous papers demonstrate a progression from décollement folding to fault-propagation folding to fault-bend folding. However, it is clear that no single kinematic model can explain the details of most natural fault-related folds. The geometries documented in this special issue are exceedingly variable, suggesting that multiple modes of fault-related folding are required to generate the diversity of geometric, kinematic and dynamic signatures contained within the structures. Although no single paradigm or consensus about the origin of fault-related folds is reached within this issue, we hope that the ideas and datasets in these papers will lead to broader perspectives on fault-related folding.

REFERENCES

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