occurs as the beds move through the system from syncline to anticline to anticline to syncline"; and (3) stating that "the literature is replete with examples which demonstrate that bed slippage occurs in nearly all fold structures and certainly occurs when beds move up over ramps". As Crane emphasized, and is documented in the literature (e.g. Chapple & Spang 1974), interbed slippage and strain certainly accompany fold development. Therefore, the assumption of "no interbed slippage or significant strain" is neither a necessary nor valid assumption for fault-bend folding.

Crane presents a model for fault-bend folding where the hangingwall and footwall cutoff angles and lengths (bed travel distance) are retained. This model produces a ramp anticline with a forelimb dip equal to the hangingwall cutoff angle, and a backlimb dip equal to the footwall cutoff angle. Crane's fig. 1(b) violates the description of the model in the text, and principle 3, because the cutoff angles in the hangingwall and footwall are not equal. The ramp-anticline forelimb is dipping at 45°, reflecting a 45° hangingwall cutoff angle, and the backlimb dip is 30°, reflecting a footwall cutoff angle of 30°.

An alternative to Crane's model is a fault-bend fold model presented by Suppe (1983) which allows bedding plane slip and is constrained by (a) preservation of layer thickness, (b) no net distortion of horizontal layers and (c) conservation of bed lengths. The fold is the product of moving the hangingwall over a non-planar fault surface. The resulting fault-bend fold is asymmetric (e.g. 60° forelimb dip and 30° backlimb dip for a fault-bend anticline with 0° flat segments and a 30° footwall cutoff angle). The hangingwall cutoff angle is dependent upon the footwall cutoff angle, the fault bend angle, and the axial angle. Figure 1 is a graph showing the per cent decrease in hangingwall cutoff length plotted versus footwall cutoff angles for Crane's model, Suppe's models for fault-bend and fault-propagation folding (Suppe 1983, 1985), and five natural examples of thrust fault related folds. Crane's model plots along the horizontal axis at 0% decrease in hangingwall cutoff length, and Suppe's models and the natural examples plot in the field of the graph. This figure illustrates that (a) some real examples of thrust-fault related folds in foreland fold-thrust belts (examples from the Variscan of England, the Southern Appalachians, the Idaho–Wyoming fold-thrust belt and the Jura) are not consistent with Crane's model, and (b) Crane's principle 3, and consequently his model, strongly disagrees with Suppe's model which has been successfully used in the construction of cross-sections for Taiwan (e.g. Suppe 1983) and the Appalachians (e.g. Mitra 1986). These observations indicate that retaining cutoff angles and lengths is not a necessity for the construction of viable and admissible cross-sections.

Use of fault cut-offs and bed travel distance in balanced cross-sections: Consolidated reply

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DISCUSSIONS by both Rowan & Ratliff and by Ferrill of the short note on section construction by keeping fault angle cut-offs and lengths equal (Crane 1987) raise some valid objections about the universal applicability of the method when evaluating the structural style of a specific structure.

The proposed model should *not* be used to explain the details of development of a particular fold. The model is the limiting simplest case as has been pointed out by De Paor (1987), Boyer & Elliott (1982), p. 1225), Rowan & Ratliff and others. This simplest case is critical because it serves as the standard for thrust belt analysis. As is shown by Ferrill (fig. 1), other models can be constructed which fit specific thrust-fold shapes and can be valid for different strains and stratigraphy. These models will plot on Ferrill's graph in different positions, are unique, and thus cannot serve as a worldwide standard.

The advantage of the proposed model is that it allows predictions. The following criteria are fulfilled:

(1) the number of assumptions is limited;

(2) sections are capable of rapid geometrical restorations;

(3) subsurface conditions can be predicted where no primary data exist;

(4) it is widely applicable to all foreland thrust belts;

(5) it allows rapid construction of required numerous cross-sections;

(6) it serves as a standard by which other variables can be investigated to explain departures in form from the ideal norm.

The model predicts subsurface configuration of cutoffs, the placement of faults and existence of potential structures. Because the model is a standard, any deviations from this standard can be instantly recognized.

Reasons for the deviation can then be related to amounts of strain, stratigraphic changes, orientation of pre-existing structures including shelf edges, old listric normal or thrust faults, backthrusts, recognition of true out-of-sequence faults, estimates of interbed slippage, mapping unrecognized bedding-plane thrusts, recognizing interference of one thrust belt by a later one, recognition of buried wrench faults, intrusions, and all the other complexities encountered in interpreting thrust belt behavior.

A necessary standard for thrust belt interpretation is a simple standard to which all other structures can be compared. All of the structures in the literature incorporate variations of stratigraphy, position in a thrust belt, varying amounts of strain, thickness and volume changes, differing amounts of folding vs thrusting, etc. The three categories mentioned by Ferrill are only part of a continuous spectrum of forms which because of one geological reason or another depart from the norm.

Rowan & Ratliff point out that significant bedding-parallel shear must be present and that the bedding-perpendicular markers shown by Crane (1987, fig. 1) did not originate as layer-perpendicular loose lines in the undeformed state. They are correct, for each axial plane marker was arbitrarily placed in this position for illustrative purposes only. Both Rowan & Ratliff and Ferrill accept Suppe's (1983) fault-bend fold model, in spite of the fact that that model requires an instantaneous change in fault cut-off angle and fault lengths as each unit passes the precise point where the ramp changes to a flat, and is therefore geologically unreasonable. Suppe also proposed several other models in addition to the one usually cited. Suppe's fig. 17, on general layer parallel shear, is essentially the same as the proposed model.

Many of the other objections raised appear to be either philosophical or are based on an interpretation of what was actually written and implied. The proposed model is a general-case standard and does not attempt to, nor can it explain, the peculiarities of any individual fold, which are in reality due to the exact location of the fold within a unique strained portion of a thrust belt with specific stratigraphy which responded uniquely to a particular applied force.

The basic test of the model should be whether it works in practice. Examination of hundreds of wells, thousands of miles of seismic sections, examination in the field of hundreds of folds, thrusts and related structures, construction of thousands of cross-sections and 30 years of interpretation of 20 different world-wide thrust belts starting from the basic concepts of Dahlstrom in the late 1950s has convinced me of the basic usefulness of the principle. A short note unfortunately does not allow for full documentation of the principle with specific field examples. As a standard case which is then modified by the specifics of the structural style of any particular thrust belt, the principle has served as a unifying concept which brings order out of chaos, and provides the foundation from which the proper questions can be asked.

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