Shortening and Shortening History in Detachment Folds determined by Thickness-relief Analysis, with examples from Tianshan and Cascadia.

Ramon A. Gonzalez-Mieres and John Suppe. Department of Geosciences, Princeton University, Princeton NJ 08544 USA

Detachment folds are among the simplest and best-imaged common folds at the front of thrust belts. Here we show how analysis of thickness variations in well-imaged detachment and other folds can be used to separate structural from stratigraphic thickness variation to obtain detailed bed-by-bed constraints on shortening and shortening history. Two examples of well imaged detachment folds are presented: [1] Yakeng anticline at the front of the southern Tianshan in the Kuche foreland basin of China and [2] an unnamed detachment fold at the front of the Cascadia subduction complex offshore Oregon USA. Our technique of "thickness-relief analysis" is derived from the concepts of Epard & Groshong (1993), in which they showed how to determined shortening from the vertical variation of area of structural relief in a structure. However their technique cannot be applied in a number of actual cases because of common stratigraphic and structural complexities that make it difficult to separate the shortening structural component of fold amplitude from other common contributors to relief, such as stratigraphic variation or basement warping. We show how suitable "vertical restoration" of the structure by flattening to key stratigraphic horizons allows us to quantitatively separate the structural and stratigraphic components of relief over limited stratigraphic intervals. We can then measure the area of the structural component of the thickness relief for each horizon. The vertical gradient in the area of thickness relief is then equal to the shortening for that interval. By making such measurements for every stratigraphic interval we obtain shortening on a bed-by-bed basis within both pre-growth and growth strata. However, the behavior of area relief shows a fundamental difference between pre-growth and growth strata. Area of relief depends on sedimentation and shortening rate in growth strata but is independent for pre-growth strata. Therefore the ratio of sedimentation rate to shortening rate ($\Delta H/\Delta S$) is key to obtaining the history of deformation from the areas of relief.

Applying this analysis to the active low-amplitude Yakeng anticline in western China shows homogeneous 1200m shortening as a function of depth within the pre-growth sequence, which lies above a 6 km deep evaporitic detachment. The analysis also shows a diapiric injection of 0.9 km^2 just above this basal detachment. The beginning of growth is identified and an upward

decrease in shortening that is a linear function of elevation, with a sedimentation rate that is 167% of the shortening rate.

The low amplitude Cascadia detachment fold shows the other hand a more complex pre-growth because of two levels of detachments. Shortening above the lower detachment is 85 m and homogeneous, whereas the shortening above the upper detachment is 250 m and homogeneous. There is no diapiric component. Modeling of the growth strata shows that shortening on the lower detachment occur later on the evolution of the fold and appears to begin with the turning off of the upper detachment. In addition, modeling the effects of change in detachment on area of structural relief shows that the observed change in $\Delta H/\Delta S$ is due to the change in depth to active detachment rather than a change in sedimentation rate, which seems to be almost constant over the deformation history.