Dual-Stage Deformation in Laramide Basement-Involved Foreland Arches

Erslev, Eric A.[*1]; Wise, Donald U.[2]; Smaltz, Sara M.[3] (1) Geology and Geophysics, University of Wyoming, Laramie, WY. (2) Geosciences, University of Massachusetts, Amherst, MA. (3) EnCana Oil and Gas, Denver, CO.

The origins of structural diversity are important for predicting fracture orientations as they can be crucial to petroleum exploration and development. Recent compilations of Laramide geometric and kinematic data show the dominance of ENE-WSW shortening, with edge effects causing more northerly shortening on the northern orogen margin and more east-west shortening on the southeastern orogen margin. These patterns are complicated by the reactivation of pre-existing weaknesses in Rocky Mountain basement rocks.

The diverse evidence for dual stage and multi-directional Laramide deformation are more difficult to explain. Previous 3-D balancing of the Boulder Flatirons in Colorado and the Sheep Mountain and Rattlesnake Mountain areas of the Bighorn Basin in Wyoming show early out-of-the-basin thrusts were cut by into-the-basin thrusts. Wise showed that early NNE shortening was followed by east-directed shortening in the Beartooth Arch, whereas Gries proposed late N-S-shortening on Laramide arches in central Wyoming. In addition, late SSW-directed Laramide slip on Beaver Creek detachment near Shell, Wyoming, contrasts with late SSE-directed slip on the South Fork detachment system across the Bighorn Basin. These contradictory directions of motion have generated hypotheses invoking everything from changes in plate motion (proposing both clockwise and counterclockwise stress rotations) to the existence of localized sticking points (e.g., the Stillwater Complex of the Beartooth Arch).

To constrain a 4-D (3-D space plus time) crustal-scale model of Laramide deformation, minor fault data were collected over the entire Bighorn Arch as part of the Bighorn Project. This NSF-EarthScope-funded collaboration seeks to determine the genesis of Laramide arches by combining detailed geologic, kinematic and 3-D passive/active seismic investigations (with 24 ~1 ton shots and ~2000 seismometers). New analyses of shortening on the eastern flank of the Bighorn arch show dual-stage motion, with ENE-WSW shortening followed by slip in directions radial to the center of the arch.

These results indicate an initial stage of roughly ENE-WSW regional shortening was experienced throughout the Laramide orogen. This was commonly dominated by out-of-the-basin thrusting and locally complicated by Precambrian weaknesses and edge effects along the Montana and New Mexico boundaries of the orogen. In areas adjacent to arch culminations, a second stage of deformation combined components of ENE-WSW shortening and gravity spreading, causing increased into-the-basin thrusting due to shortening roughly radial to arch culminations. This dual-stage hypothesis suggests that local gravitational potential partially drove late Laramide structures. This model may be valuable in predicting fractures critical to oil and gas resource plays.