Mid-Crustal Detachment in the Rockies: Results from the EarthScope/NSF Bighorn Project

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The Bighorn Project addressed the question of cratonic rheology by documenting the 3D geometry and kinematics of the Laramide Bighorn Arch, a minimally-reworked, contractional foreland arch in the northern Rocky Mountains. Enigmatic basement-involved arches occur adjacent to diverse collisional orogens, including those formed by low-angle subduction and continental collision. Current hypotheses include crustal block translation and rotation on through-going faults, crustal detachment, lithospheric buckling, and pure shear thickening. The deeper geometries and kinematics of these foreland arches are highly contested due to a lack of detailed arch- and crustal-scale geophysical imaging and structural studies.

The Bighorn Project tested these hypotheses with a 3D active/passive seismology experiment (BASE – Bighorn Arch Seismic Experiment), gravity modeling and arch-scale kinematic data collection and modeling. Seismic tomography and gravity models show upper crustal thickening under the arch, with shallow low-velocity and low-density regions bounding the arch that may correspond to zones of Laramide deformation. 3D analyses of passive receiver function data (3 arrays with up to 850 seismometers) integrated with active reflection/refraction data (24 shots, 1800 seismometers) reveal an unfaulted, continuous Moho and a heterogeneous lower crust with discontinuous patches of high velocity (>7 km/s) crust quite unlike the continuous slab of high velocity lower crust to the west. The Moho surface is arched under the northern Bighorn Arch, but this arch trends NE, at a high angle to NNW-trending Laramide arching defined by folded pre-Laramide strata. Because the Moho arch parallels Precambrian tends, not Laramide trends, local Moho arching is probably Precambrian in age.

Slickensided faults, paleomagnetics and structural balancing show that regional Laramide ENE-WSW compression was modified by local gravity spreading of the arch high. The asymmetrical, ENE-verging arch geometry combined with depth-to-detachment calculations indicates Laramide detachment of the upper crust at ~30 km depth. Complex shear wave splitting in the mantle below suggests intact Precambrian mantle lithosphere without wholesale Phanerozoic modification. The Bighorn master thrust, with associated rotational fault-propagation folding, ramped off that detachment, thickening the upper crust and forming the Bighorn Arch. We propose that many contractional, basement-involved foreland thrust belts probably formed above mid-crustal detachments rooted in the hinterland of adjacent collisional mountain belts. The origins and rheological controls on mid-crustal zones of weaknesses in these collisional forelands are still unexplained.