Decoupling near the moho: weakening beneath rigid mantle or lower crustal layers in thickened mountain roots and extensional zones

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Continental deformation which changes crustal thickness results in decoupling near the crust–mantle boundary (MOHO). Decoupling results from rheological weakening of distinct lithologies, and thermal structure, and can occur above or below the MOHO.

The depth and width of a continental collisional orogenic belt depends upon the forces of plate convergence, the distribution of rheological layering in the lower crust, and the brittle to ductile rheological evolution in the subMOHO ultramafic mantle. Immediately after continental collision, the mantle below the thickened continental root (from 70 to ~100 km depth) is significantly colder and consequently stronger (~1500 MPa) than adjacent mantle. This indicates that sub-root mantle represents a first order rheological boundary during the later stages of convergence.

The stability of the deepened MOHO depends upon the geothermal gradient and rheological state just before thickening, and whether the lower crust is felsic (diorite) or mafic (diabase <35 km, eclogite >35 km). For average geothermal gradients and continents doubled from 35 km thickness after nearly 20 Ma of incubation, the root mantle and adjacent shoulder mantle have similar strength. After this time the root mantle layer supporting the thickened continent is no longer rigid and strong. For thinner continents, and more so for those still thermally softened during extension just before thickening, the weakening of the rigid upper most depressed root mantle occurs in less than 10 Ma.

The evolution of thermal structure in an orogen during continuous convergence is responsible for changes of strength distribution. Therefore, stress transmission through the orogen changes from an early strong wedging stage, towards a thickened-root weak stage. Such a strength evolution may play an important role in the possible mechanical behavior of forelands.

A lithospheric buckling model for the Laramide orogeny

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During the Laramide orogeny (75–50 Ma) in Western North America, foreland deformation in the form of arches or antiformal uplifts occurred throughout the eastern Rocky Mountains region. The same structural style developed east of the foreland in the midcontinent region, and extends from the Gulf of Mexico to approximately the US/Canadian border (49° N). Initiation of foreland and mid-continent arches appears generally to be older in the south and younger in the north. We attribute the deformation in the Rocky Mountain foreland and continental interior to folding of the entire lithosphere (lithospheric buckling). The observed wavelength of arches in the western United States is ~150–190 km, a spacing consistent with a lithospheric buckling interpretation. Where late-stage Laramide deformation has not obscured early Laramide structures, arches show a tightening from an initial wide uplift to a narrower, greater amplitude antiform; this observation is also consistent with scaled lithospheric models for buckle development.

The earliest of the Rocky Mountain foreland arches are NS oriented, at a high angle to ENE oriented Precambrian boundaries (e.g., Archean Wyoming province vs. Proterozoic Colorado terranes), that might be expected to control arch geometry. Although some evidence exists for reactivation of old (Precambrian to Paleozoic) crustal structures during Laramide foreland deformation, the overall style of deformation of the uplifts seems to be more strongly controlled by buckling geometry than by pre-existing structure.

This buckling model provides a mechanical explanation for the distinction between

- "thin-skinned" Sevier-style and contemporaneous and younger
- "thick-skinned" Laramide-style deformation,

which depends upon the decoupling or coupling of the lithospheric layers.

The classic tectonic model for formation of the Laramide Orogeny involves shallow subduction of a Cretaceous oceanic plate (Farallon plate) beneath North American crust. In this model, shear must be transmitted directly to the overlying crust to produce contractional structures far from the continental margin, requiring stripping of mantle lithosphere. The buckling model presented here better explains the collisional "style" of the orogeny, and is uniquely consistent with the observation of mantle xenoliths that require preservation of western North America's mantle lithosphere throughout the orogeny.

Additionally, growing evidence for dextral shearing within the foreland block uplifts suggests an alternate model for oblique terrane accretion as the ultimate cause of the Laramide orogeny.

Inversion tectonics in the Central Apennine fold and thrust belt

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Structural evolution in the Central Apennines is traditionally considered to have resulted from thrusting of sedimentary cover along a major sub-horizontal detachment above a magnetic, crystalline basement. Models based on this hypothesis typically predict that large displacements (>150 km or 40 %) have occurred as a result of this. Alternatively, exactly the same surface geology and well data can be reinterpreted using a basement-involved, inversion tectonic model with relatively low displacement. In such a model, reactivation of Mesozoic and Tertiary extensional faults occurred during Miocene compressional deformation in the overall context of Africa–Europe collision.

Several lines of evidence support an inversion model for the structure of this Central Apennine area. The pre-existing rifted architecture is demonstrated by abrupt lateral variations in facies and thickness of the stratigraphy. Analysis of geological maps of key areas reveals the presence of short-cut thrust faults in the footwalls of pre-compressional normal faults. Some thrusts have small-scale structures indicating NE vergence and yet show net extensional throws of the Mesozoic stratigraphy (e.g., the Filletino–Vallepietra thrust: Cretaceous in the hangingwall against Triassic in the footwall). This configuration is consistent with compressional reactivation of a pre-existing normal fault where the extensional displacement was greater that the thrust displacement.

The large displacements predicted by detachment-style models require the formation of a hypothetical passive-roof duplex at the mountain front, yet such structures are considered to be mechanically unlikely. In contrast, the lower displacement involved in an inversion model means that such structures are not required. Furthermore, the CROP deep seismic line across the Tuscany/Marche Apennines shows that the basement and Moho are imbricated as a result of compression in that part of the thrust belt; again, this is consistent with inversion tectonics.

This poster contrasts an existing detachment-style model and the new inversion model using balanced cross-sections through the Central Apennines. The inversion model has been constructed to incorporate the features described above, and is further supported by seismic data from the Adriatic foredeep which has similar characteristics.