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Lithosphere Gravitational Instability and Its Surface Expression in Continental Plateaux

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Continental plateaux, such as the central Andes and Tibet, develop through shortening and crustal thickening, resulting in high elevations. On a local scale, the central Andes is characterized by several hinterland basins that stand out as areas of relatively low elevation within the modern plateau (Horton, 2012). There are also examples of basins in the geological record, such as the Miocene Arizaro basin (21-9 Ma), which formed as a nearly circular ~100 km wide basin and filled with 3 km of sediments that record minor internal shortening (DeCelles et al., 2011). It was then exhumed and now sits several hundred meters higher than its surroundings. In contrast, the Tibetan plateau has a relatively low surface relief and such basins have not been found here.

In this study, we address the formation of local hinterland basins in a continental plateau. In the central Andes, the basins are enigmatic features that can not be clearly linked with neighboring thrust-faulted uplifts, loading associated with orogenesis, or extension (Carrapa et al., 2009; Canavan et al., 2010). Instead, it has been proposed that the basins are caused by gravitational removal of a localized high-density region in the plateau lithosphere (i.e., a Rayleigh-Taylor-type drip) (DeCelles et al., 2011). The high density material could be related to metamorphic eclogitization of thick, metastable granulitic lower crust (Austrheim, 1991; Bousquet et al., 1997), emplacement of eclogitic magmatic restites at the base of crust (Ducea, 2002; Kay and Coira, 2009), or local perturbation at lithosphere-asthenosphere-boundary (LAB) formed during orogenic compression (e.g., Houseman and Molnar, 1997).

We use 2D thermal-mechanical models (Fullsack, 1995) to study the dynamics of gravitational removal of high-density lithosphere and the effect on surface topography. The numerical models include continental lithosphere with a pre-thickened crust (~72 km thick) and a thermal structure consistent with geophysical observations (e.g. Currie and Hyndman, 2006). All materials have a viscous plastic rheology with laboratory-derived viscous parameters of quartz (upper-mid crust), diabase (lower crust) and olivine (mantle lithosphere). Two crustal strengths (strong and weak) are tested by linearly scaling the effective viscosity of the crust. A high-density root region is placed in either in lower crust or mantle lithosphere. This is taken represent high-density rocks associated with metamorphic/magmatic process or perturbation of LAB. At the start of the models, the root has the same density as its adjacent layer. As the model runs, the density of this region increases at a prescribed rate to simulate either progressive eclogitization associated with kinetically delayed metamorphism (crustal root), or emplacement of high-density magmas or a growing perturbation of the LAB (mantle root).

In all models, the root becomes gravitationally unstable and detaches from the lithosphere. Generally, three types of surface deflection are observed as the root is removed: (1) significant subsidence above the root (>500 m), followed by uplift, (2) little subsidence, and (3) uplift followed by collapse. The main control on surface deflection is the viscous coupling between the root and surface, which decreases with increasing root depth or weaker crust. For the range of parameters tested in our models, we find transient, localized basins form if the crust is strong and the gravitationally unstable root is located in the thick crust. In this case, stresses associated with root removal can be transmitted through the crust, perturbing the surface. If the crust is weak or the root is located in the mantle lithosphere, the magnitude of surface deflection is less than 500 m. The models show that weak crust is entrained by the gravitationally unstable root, causing crustal flow toward the root region and crustal

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thickening. For a crustal root, the rate of flow approximately balances the root removal rate, results in little surface deflection. For a mantle lithosphere root, the crustal flow is greater, leading to surface uplift. After the root detaches, the crust relaxes and the topographic high collapses.

In summary, we find that crustal strength is a key parameter that controls whether surface topography can be affected by the dynamics of the deep lithosphere. When the crust is weak, induced crustal flow can erase the surface expression of a gravitational removal event originating in either lower crust or mantle lithosphere. In Tibet, the thick crust is believed to be hot and weak, with crustal channel flow (Zhao et al., 2012). Therefore, we expect that surface topography may not be a good indicator of the occurrence of RT-type drips in this region. Conversely, the central Andes has numerous examples of local basins, both at present and in the geological record. Our models predict that such basins can be generated by RT-type drips if the central Andes crust is relatively strong.

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Key words: gravitational instability, drip, surface topography, hinterland basin

References

Austrheim, H., 1991. Eclogite formation and dynamics of crustal roots under continental collision zones. Terra Nova, 3: 492-499.

Beaumont, C., Nguyen, M.H., Jamieson, R.A., and Ellis, S., 2006. Crustal flow modes in large hot orogens. Geological Society, London, Special Publications, 268: 91–145.

Bousquet, R., Goff, B., Henry, P., Le Pichon, X., and Chopin, C., 1997. Kinematic, thermal and petrological model of the Central Alps: Lepontine metamorphism in the upper crust and eclogitisation of the lower crust. Tectonophysics, 273: 105–127.

Canavan, R., Clementz, M., Carrapa, B., Quade, J., DeCelles, P. G., Schoenbohm, L.M., and Boyd, J., 2010. Paleoelevation of the Puna Plateau, northwestern (NW) Argentina inferred from deuterium isotopic analyses of volcanic glass. AGU Fall Meeting, Abstracts, PP13B-1525, 1: 1525.

Carrapa, B., and DeCelles, P.G., Reiners, P.W., Gehrels, G.E., and Sudo, M., 2009. Apatite triple dating and white mica 40Ar/39Ar thermochronology of syntectonic detritus in the Central Andes: A multiphase tectonothermal history. Geology, 37(5): 407-410.

Currie, C.A., and Hyndman, R.D., 2006. The thermal structure of subduction zone back arcs. Journal of Geophysical Research, 111(B08404), doi: 10.1029/2005JB004024.

Ducea, M.N., 2002. Constraints on the bulk composition and root foundering rates of continental arcs: A California arc perspective. Journal of Geophysical Research, 107(B11): 2304, doi: 10.1029/2001JB000643.

DeCelles, P.G., Carrapa, B., Horton, B.K., McNabb, J, and Boyd, J., 2011. Cordilleran hinterland basins as recorders of lithospheric removal in the Central Andes. AGU Fall Meeting, Abstracts T13I-06, 1: 06.

Fullsack, P., 1995. Arbitrary Lagrangian-Eulerian formulation for creeping flows and its application in tectonic models. Geophysical Journal International, 120(1): 1-23.

Horton, B.K., 2012. Cenozoic evolution of hinterland basins in the Andes and Tibet, in Busby, C.J., and Azor, A., eds., Tectonics of Sedimentary Basins. Recent Advances, First Edition, Blackwell Publishing Ltd.: 427-444.

Houseman, G.A., and Molnar, P., 1997. Gravitational (Rayleigh-Taylor) instability of a layer with non-linear viscosity and convective thinning of continental lithosphere. Geophysical Journal International, 128(1): 125-150.

Kay, S.M., and Coira, B.L., 2009. Shallowing and steepening subduction zones, continental lithospheric loss, magmatism, and crustal flow under the Central Andean Altiplano–Puna Plateau. Geological of America Memoir, 204(11): 229-260.

Zhao, G., Unsworth, M.J., Zhan, Y., Wang, L., Chen, X., Jones, A.G., Tang, J., Xiao, Q., Wang, J., Cai, J., Li, T., Wang, Y., and Zhang, J., 2012. Crustal structure and rheology of the Longmenshan and Wenchuan Mw 7.9 earthquake epicentral area from magnetotelluric data.Geology, 40(12): 1139-1142.