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Evolution of the geotherm during extension as sedimentation and deep crustal flow compete for space

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Zones of continental extension on Earth create a wide variety of tectonic phenomena because they affect various sections of lithosphere, from rifting of cold cratonic crust to extension of hot orogenic domains. As a result, extension zones develop a variety of thermomechanical responses that translate into different styles of basin sedimentation and varied characteristics of brittle deformation and ductile flow. We explore this range of responses of lithosphere to extension in a suite of numerical models using Underworld. The lithosphere comprises continental crust (40 or 60 km thick), including 20 km shallow crust (brittle), and the underlying deep crust has starting viscosities corresponding to STRONG, INTERMEDIATE, and WEAK. The initial Moho T is 600C. Extension velocities of 10 mm/yr are applied to each side of the lithosphere (20 mm/yr total), and models are run for 10 million years corresponding to a maximum mean extension of 55%. A sedimentation function allows sediment of density 2620 kg/m3 to be deposited in depressions at the crust-air interface; the sedimentation function is turned on or off in order to isolate the effect of basin development on rifting.

In spite of the number of parameters that are varied across the models, some general characteristics emerge. A WEAK deep crust favors localization of strain in the shallow crust, resulting in the formation of a wide metamorphic core complex, particularly when the starting crust is thick (60 km). In this case the geotherm is extremely perturbed at the center of the model, with T at 10 km reaching ∼400C after 2 Myr of extension and 600C after 8 Myr. Basins in these models remain shallow (<5 km) and undergo prograde metamorphism at their base (up to 350C). In comparison, when deep crust is STRONG or INTERMEDIATE, it is not exhumed so efficiently, and T at 10 km depth in the center of the model reaches only 200-250C. When basins are deposited, heat advection from deep crustal flow is suppressed, and the geotherm remains cooler; however, basins are now deeper (sedimentation competes favorably with deep crustal flow to accommodate extension space), and the base of basins can undergo modest metamorphism. The behavior of 40 km thick crust is quite different. Extension of the shallow crust is now distributed, with the production of graben and tilted crustal blocks. Basins develop effectively in zones of lithosphere necking, to the point that the Moho and the base of the lithosphere are rapidly exhumed, especially in the cases of STRONG and INTERMEDIATE deep crust. The transient geotherm shows extreme lateral variations depending on the extent of necking, and T at the base of basins varies accordingly (up to 500C). In this case, results also show that localization of rifting ultimately leads to drifting after only a few million years of extension. Overall, these results show that basin sedimentation and flow of deep crust compete to accommodate extension and that the evolving geotherm reflects this competition.