Geophysical Research Abstracts
Vol. 20, EGU2018-7626, 2018
EGU General Assembly 2018

Evolving lithospheric flexure and paleotopography of the Pyrenean Orogen from 3D flexural modeling and basin analysis

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The Pyrenees are an asymmetric, doubly-vergent orogen with retro- and pro- foreland basins that preserve a record of deformation since the Mesozoic. The extensive research and exploration efforts on the mountain belt and flanking foreland basins provide an exceptional dataset for investigating geodynamics and surface processes over large spatial and temporal scales in western Europe. We present the results of a numerical modeling study investigating the spatio-temporal variation in lithospheric flexure in response to the developing orogen. We employ the finite element method to model the 3D flexural deformation of the lithosphere beneath the Pyrenean orogen since the onset of convergence in the late Cretaceous. Using subsurface, geophysical, and structural data, we describe the evolving geometry of both the French Aquitaine and Spanish Ebro foreland basins at the present (post-orogenic), the Oligocene (late orogenic), the top and mid-Eocene (peak orogenic), and the Paleocene (early orogenic). The flexural modeling provides insight into how both the rigidity of the lithosphere and the paleotopographic load have varied over the course of orogenesis to shape the basin geometry. We find that the overriding European plate has slightly higher rigidity than the subducting Iberian plate, with modern Effective Elastic Thickness (Te) values of 22 $\pm$ 1 and 18 $\pm$ 1 km, respectively, and an RMSE of 450 m. Our results indicate minimal to negligent plate boundary forces are necessary to fit the data, consistent with thermo-mechanical modeling. Flexural modeling results suggest that the topographic load increased 200% from the Paleocene to the Oligocene, reaching modern levels by the end of the Eocene. Following the Eocene, the topography was relatively stable, with only minor topographic growth and decay. These results contrast with low-temperature thermochronology data, which indicate continued rock exhumation until the Miocene. Our results suggest the Pyrenees have been in topographic steady state since the end of the Eocene, but with variable exhumation and erosion rates across the orogen. These results have implications for surface processes and foreland basin development of the Pyrenean Orogen, tectonic inheritance, and the geodynamic evolution of western Europe.