Ultra-slow transverse waves during continental extension: A numerical model of the rift-drift transition

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Continental rifting is one of the four fundamental geological processes of the Wilson cycle. Rifting results from the continuous stretching of a continental mass and involves mechanical, thermodynamic, and rheological processes. It may last several tens Myrs and be followed by a catastrophic breakup stage (drifting), which determines cessation of continuous deformation and the final separation of a continent into two distinct tectonic plates that grow by accretion of oceanic lithosphere. To date, the transition to sea-floor spreading and the conditions for the development of a new ocean have not been fully understood. We present numerical experiments showing that a nonlinear viscoelastic model of the cratonic lithosphere, allowing accumulation of elastic strain over several Myrs, may explain the major features of the rift-drift transition. The model incorporates thermodynamic effects associated with viscous shearing, showing how thermal anomalies generated in the lithosphere during rifting play a major role in the break-up style. A fundamental result of the experiments is that extension is always accompanied by transverse material waves in the lithosphere, with wavelengths of the order of thousands km and periods of several tens kyrs. These waves induce an oscillating topography and could be responsible for high-frequency transgressive-regressive cycles in rift lakes. At sufficiently high extension rates, deformation localizes and these ultra-slow waves determine cyclic shear failure, with formation of X-shaped cross structures through the lithosphere that prelude to the final rupture. A comparison with the Red Sea evolution shows that onset of extension could be older than the widely accepted age of 27-30 Ma and that an older phase of uniform stretching without localization could have preceded the formation of a rift valley.