Breaking a single-plate Earth into a global plate network

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Fifty years after the main discovery period for plate tectonics, we still lack a consensus understanding of a critical question: how did the plate tectonic system initiate? For the period before initiation of plate tectonics, models increasingly call upon a stagnant lid (i.e., a single-plate lithosphere) atop a mantle which was hotter by a few hundred degrees than the present mantle. How was this lid first broken into plates? Various hypotheses suggest that the strength of the lid was overcome by (a) mantle convective forcing, potentially along locally pre-weakened zones, (b) lithospheric gravitational instabilities between oceanic lithosphere and either adjacent oceanic plateau lithosphere or adjacent overthickened (i.e., gravitationally collapsing) continental lithosphere, or (c) one or more large bolides. These models have not converged on a mechanism or a typical early plate scale. Here, we use a new solid-mechanics based approach to the problem of the origin of plate tectonics and the processes by which plate boundaries are initiated. Specifically, we employ 3D spherical shell models of a brittle lithosphere via the three-dimensional finite element code RFPA (Rock Failure Process Analysis code). The models are subjected to quasi-static, slowly increasing interior pressure in a displacement-controlled manner (e.g., induced by gradual thermal expansion). Brittle failure is implemented through a strength criterion representing a stress limit at which the strength drops and fracture occurs. To account for local randomness, each element is assigned a failure threshold obtained from a Weibull probability distribution which contains a parameter describing the degree of material homogeneity. Globe-spanning rifting occurs as a consequence of horizontal extension. Resultant fracture spacing is a function of lithospheric thickness and rheology, such that geometrically-regular, polygonal-shaped tessellation is energetically favored because it minimizes total crack length. Therefore, anticipated warming of the early lithosphere itself (as lithospheric chilling from downwards advection due to rapid volcanism wanes) should lead to failure, propagating fractures, and the conditions necessary for the onset of multi-plate tectonics.