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Lithosperic rheology controls on oceanic spreading patterns

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Mid-ocean ridges sectioned by transform faults represent one of the most prominent surface expressions of terrestrial plate tectonics. A fundamental long standing problem of plate tectonics is how and why ridge-transform spreading patterns are formed and maintained. On the one hand, geometrical correspondence between mid-ocean ridges and respective rifted margins apparently suggests that many oceanic transform faults are inherited structures that persisted throughout the entire history of oceanic spreading. On the other hand, data from incipient oceanic spreading regions show that transform faults are not directly inherited from transverse rift structures and start to develop as or after oceanic spreading nucleate. Based on self-consistent 3D thermomechanical numerical model of oceanic spreading we demonstrate that only limited range of oceanic lithosphere rheologies can reproduce natural spreading patterns. In particular, spontaneous formation and long-term stability of orthogonal ridge-transform spreading pattern requires visco-brittle/plastic rheology of plates with strong dynamic weakening of spontaneously forming faults. Our, numerical models of incipient oceanic spreading demonstrate that one or several oceanic transform faults can form gradually within broad non-transform accommodation zones connecting initially offset spreading centers. Orientation of transform faults and spreading centers changes exponentially with time as the result of new oceanic crust growth. The resulting orthogonal ridge-transform system is established within few millions of years after the beginning of oceanic spreading. By its fundamental physical origin, this system is a crustal growth pattern governed by space accommodation and not a plate breakup pattern governed by stress distribution. It is demonstrated that the characteristic extension-parallel orientation of oceanic transform faults can be obtained from space accommodation criteria as a steady state orientation of a strike-slip fault sustaining in between simultaneously growing offset crustal segments. Numerical models also suggest that transform faults can develop at single straight ridge as the result of dynamical instability of constructive plate boundaries caused by weakening of forming brittle/plastic fractures. Boundary instability from asymmetric plate growth can spontaneously start in alternate directions along successive ridge sections; the resultant curved ridges become transform faults within a few million years. Offsets along the transform faults change continuously with time by asymmetric plate growth and discontinuously by ridge jumps. Degree of asymmetric plate accretion increases with increasing degree of brittle/plastic weakening. It is also strongly dependent on the brittle/plastic yielding criterion and is notably reduced in models with pressure-dependent brittle/plastic plate strength compared to models with pressure-independent strength.