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Triple junctions and multi-directional extension of the lithosphere

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Triple junctions are among the most remarkable features of global plate tectonics but their nucleation and evolution remains debatable. Divergent (R-R-R) triple junctions (at 120o and T junctions) are particular ones since their stability depends on the exact values of the relative velocities of multi-directional plate motions and hence is strongly affected by plate rheology and processes of crustal and lithospheric accretion. It is commonly accepted (although not quantitatively tested) that the geometry and stability of R-R-R triple junctions should be related to the intuitive geometric considerations that 3-branch configurations should be more "stable" compared to >3-branch configurations (e.g. quadruple junctions) under conditions of long-term multi-directional extension on a 3D Earth surface. Indeed, it has been long-time suggested that triple junctions result from evolution of short-lived quadruple junctions, yet, without providing a consistent mechanical explanation or experimental demonstration of this process, due to the rheological complexity of the breaking lithosphere subsequently subjected to complex oceanic crustal and lithospheric accretion processes. Therefore, a complete 3D thermo-mechanically consistent approach is needed to understand the processes of formation of multi-branch junctions.

Here, we study numerically the processes of multi-branch junctions formation under condition of multi-directional lithospheric extension. We use high-resolution 3D numerical magmatic-thermo-mechanical experiments that take into account realistic thermo-rheological structure and rheology of the lithosphere and account for crustal and lithospheric accretion processes. We find that two major types of quadruple and triple junctions are formed under bi-directional or multidirectional far-field stress field: (1) plate rifting junctions are formed by the initial plate fragmentation and can be subsequently re-arranged into (2) oceanic spreading junctions controlled by the new oceanic crust and lithosphere accretion. We document initial formation and destabilization of quadruple R-R-R-R junctions as initial plate rifting structures under bi-directional extension. In most cases, quadruple plate rifting junctions rapidly (typically within 1-2 Myr) evolve towards formation of two diverging triple oceanic spreading junctions connected by a linear spreading center lengthening with time. Asymmetric stretching results in various configurations, for example formation of “T-junctions” with trans-extensional components and combination of fast and slow spreading ridges. Numerical experiments also suggest that several existing oceanic spreading junctions form as the result of plate motions rearrangements after which only one of two plates spreading along the ridge becomes subjected to bi-directional spreading. Combined with plume impingement, this scenario evolves in realistic patterns closely resembling observed plate dynamics. In particular, opening of the Red Sea and of the Afar rift system find a logical explanation within a single model. We also demonstrate that the development of triple junctions should be an intrinsic feature of subduction and plate tectonics initiation triggered by plume-lithosphere interactions.