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Magmatism at passive margins: Effect of depth-dependent rifting and depleted continental lithospheric counterflow

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Rifted continental margins may have a variety of structural and magmatic styles, resulting in narrow or wide, magma-dominated or magma-poor conjugate margins. Some magma-poor margins differ from the classical uniform extension (McKenzie) model in that continental crust breaks up significantly earlier or later than continental mantle lithosphere and establishment of mature mid-ocean ridge is significantly delayed. The best-known examples are observed at: 1) the Iberia-Newfoundland conjugate margins (Type I) with a narrow transition between oceanic and continental crust; and 2) ultra-wide central South Atlantic margins (Type II) where the continental crust spans wide regions while the mantle lithosphere beneath has been removed. These margins are explained by depth-dependent extension. In this study, we perform 2D thermo-mechanical finite element numerical experiments to investigate magmatism at passive margins with depth-dependent extension. A melting prediction model is coupled with the thermo-mechanical model, in which temperature, density and viscosity feedbacks are considered. For the standard models, the crust is either strong and coupled (Type I-A models), or weak and decoupled (Type II-A models) with mantle lithosphere. In addition, models with a buoyant, depleted (cratonic) lower mantle lithosphere (referred as C models) are also investigated. We illustrate that Type I-A/C models develop Type I narrow margins, whereas Type II-A/C models develop Type II wide margins. In the C models, the buoyant lower mantle lithosphere flows laterally towards the ridge (i.e. the counterflow), resulting in the exhumation (in Type I-C models) or underplating (in Type II-C models) of the continental mantle lithosphere. Magmatic productivity is strongly prohibited when counterflow is developed. We argue that Type I-A and I-C models are comparable with the Aden Gulf rifted margins and the Iberia-Newfoundland conjugate margins, respectively. The Type II-A/C models are consistent with some ultra-wide South Atlantic margins, with or without extrusive igneous crust.