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A tectonic model for sequential faulting, crustal thinning, and the development of asymmetric rifted margins

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Many continental margins of the world exhibit little evidence for magmatism during rifting, and are commonly known as 'non-volcanic' (NVMs). While such margins are commonly found world-wide, their tectonic evolution is still a matter of much debate. Here we use observations from pre-stack depth migrated data from the archetypical non-volcanic West Iberia-Newfoundland margins, to infer that if faulting becomes progressively sequential in time, the so-called "extension discrepancy" between horizontal extension by faulting and crustal thinning, and the asymmetric structure of conjugate margin pairs can be explained with simple Andersonian faulting. To demonstrate this we have developed a new kinematic reconstruction methodology, as commercially available balancing software require the decoupling of upper from lower crustal deformation, and cannot simulate the fault-controlled crustal-scale thinning interpreted from our data. Our balanced kinematic rift model accounts for the progressive focusing of faulting towards the basin centre, lower crustal embrittlement and the geometry of structures on seismic images. Our model differentiates two stages: A rift basin stage, where faulting is distributed across numerous disconnected, short faults with no dominant inward or outward sense of dip and a following rifted margin stage, where faulting acquires a unique sense of dip and becomes progressively sequential in time. Our model reproduces the tectonic evolution from moderately extended basins, such as the North Sea and Gulf of Suez, to hyper-extended, asymmetric margins like the West Iberia-Newfoundland conjugates without the need for large-scale detachment faults and/or differential extension of upper and lower crust.