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On the Origin of Transform Fault and Fracture Zone Deformation and Relief

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After their recognition by Menard in the early 1950s, Fracture Zones played a major role in the development of plate tectonic concepts. However, following their plate tectonic classification as the inactive scars from transform fault offsets at mid-ocean ridges, the mechanisms for their formation and evolution have been mostly overlooked by the marine geology community, and fracture zones are now often regarded as structures frozen within strong oceanic lithosphere. The role of thermal stress on shaping deformation in the oceanic lithosphere has largely shared a similar fate; while it is widely appreciated that cooling of the oceanic lithosphere leads to seafloor subsidence with age and is the origin for compressive intraplate stresses in young oceanic lithosphere, the significance of thermal strains for transform and fracture zone relief, even on ridge segmentation itself, is no longer an active field of research.

To reassess the role of thermal stresses and strain in shaping transform and fracture zone relief, we have recently been exploring numerical elasto-visco-plastic models that include the effects of thermal contraction. As an oceanic plate cools with age, it wants to contract in all directions. Net contraction in the vertical direction can be compensated isostatically. Net contraction in the spreading direction can be compensated by a little more tectonomagmatic spreading. Contraction in the ridge-parallel direction leads to build-up of thermal stress that cannot be compensated by deformation at the boundaries of the lithosphere. If the stresses induced by thermal contraction exceed the Mohr-Coulomb brittle yield stress envelope, then the effects of rock failure can be treated as 'Mohr-Coulomb Plasticity'. The 2-D numerical models we explore here treat the evolution of a ridge-parallel section of lithosphere as it ages and cools, including elastic, Mohr-Coulomb-plastic, and viscous effects. They suggest that ridge-parallel horizontal contraction, while present, does not lead to the largest topographic responses when weaker transform or fracture zone heterogeneties exist within cooling oceanic lithosphere. Instead, thermal flexure does, as proposed by Parmentier and Haxby, JGR, 1986, building upon earlier conceptual ideas of Turcotte (JGR, 1974). We use the observational approach developed by Wessel and Haxby (1990) to assess how well these 2D elasto-visco-plastic models fit observed geoid and topography anomalies across large-offset transform/fracture zone systems, in particular the long-term evolution of both isolated (e.g. Udintsev FZ) and multiple offset (e.g. Pioneer FZ-Mendocino FZ system) systems.

Initial results imply that thermal flexure is a major factor shaping fracture zone relief and geoid anomalies. It further implies that fracture zones continue to deform – and remain relatively weak – as the oceanic lithosphere ages, with important implications for later deformation of old oceanic lithosphere.