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Extensional crustal tectonics and crust-mantle coupling, a view from the geological record

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In passive margins or back-arc regions, extensional deformation is often asymmetric, i.e. normal faults or extensional ductile shear zones dip in the same direction over large distances. We examine a number of geological examples in convergent or divergent contexts suggesting that this asymmetry results from a coupling between asthenospheric flow and crustal deformation. This is the case of the Mediterranean back-arc basins, such as the Aegean Sea, the northern Tyrrhenian Sea, the Alboran domain or the Gulf of Lion passive margin. Similar types of observation can be made on some of the Atlantic volcanic passive margins and the Afar region, which were all formed above a mantle plume. We discuss these contexts and search for the main controlling parameters for this asymmetric distributed deformation that imply a simple shear component at the scale of the lithosphere. The different geodynamic settings and tectonic histories of these different examples provide natural case-studies of the different controlling parameters, including a pre-existing heterogeneity of the crust and lithosphere (tectonic heritage) and the possible contribution of the underlying asthenospheric flow through basal drag or basal push. We show that mantle flow can induce deformation in the overlying crust in case of high heat flow and thin lithosphere. In back-arc regions, the cause of asymmetry resides in the relative motion between the asthenosphere below the overriding plate and the crust. When convergence and slab retreat work concurrently the asthenosphere flows faster than the crust toward the trench and the sense of shear is toward the upper plate. When slab retreat is the only cause of subduction, the sense of shear is opposite. In both cases, mantle flow is mostly the consequence of slab retreat and convergence. Mantle flow can however result also from larger-scale convection, controlling rifting dynamics prior to the formation of oceanic crust. In volcanic passive margins, in most cases normal faults dip toward the continent. This asymmetry may either result from the mantle flowing underneath regions evolving above a migrating plume, such as the Afar, when an asymmetry is observed at the scale of the rift, or from necking of the lithosphere when the conjugate margins show an opposite asymmetry. We summarize the various observed situations with normal faults dipping toward the continent ("hot" margins) or toward the ocean ("cold" margins) and discuss whether mantle flow is responsible for the observed asymmetry of deformation or not. Slipping along pre-existing heterogeneities seems a second-order phenomenon at lithospheric or crustal scale, except at the initiation of rifting.