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Distributed and localized horizontal tectonic deformation as inferred from drainage network geometry and topology: A case study from Lebanon

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Partitioning of horizontal deformation between localized and distributed modes in regions of oblique tectonic convergence is, in many cases, hard to quantify. As a case study, we consider the Dead Sea Fault System that changes its orientation across Lebanon and forms a restraining bend. The oblique deformation along the Lebanese restraining bend is characterized by a complex suite of tectonic structures, among which, the Yammouneh fault, is believed to be the main strand that relays deformation from the southern section to the northern section of the Dead Sea Fault System. However, uncertainties regarding slip rates along the Yammouneh fault and strain partitioning in Lebanon still prevail.

In the current work we use the geometry and topology of river basins together with numerical modeling to evaluate modes and rates of the horizontal deformation in Mount Lebanon that is associated with the Arabia-Sinai relative plate motion. We focus on river basins that drain Mount Lebanon to the Mediterranean and originate close to the Yammouneh fault. We quantify a systematic counterclockwise rotation of these basins and evaluate drainage area disequilibrium using an application of the χ mapping technique, which aims at estimating the degree of geometrical and topological disequilibrium in river networks. The analysis indicates a systematic spatial pattern whereby tributaries of the rotated basins appear to experience drainage area loss or gain with respect to channel length.

A kinematic model that is informed by river basin geometry reveals that since the late Miocene, about a quarter of the relative plate motion parallel to the plate boundary has been distributed along a wide band of deformation to the west of the Yammouneh fault. Taken together with previous, shorter-term estimates, the model indicates little variation of slip rate along the Yammouneh fault since the late Miocene. Kinematic model results are compatible with late Miocene paleomagnetic rotations in western Mount Lebanon. A numerical landscape evolution experiment demonstrates the emergence of a similar χ pattern of drainage area disequilibrium in response to progressive distributed shear deformation of river basins with relatively minor drainage network reorganization.