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Comparing fault-interaction modeling and topographic metrics to better understand the tectonic evolution with an example from the south-central Alborz mountains, Iran

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In various tectonic settings, composite landscapes, including inherited, tectonically overprinted, and newly generated topographic features can be expected. While fault networks might be assumed to be relatively static, the stress conditions might change over time.

How long landforms in such composite landscapes might persist will largely depend on the vigor of surface processes and the magnitude of change in the boundary conditions. Against the backdrop of such response-time problems it is difficult to use landforms as proxies for ongoing tectonism, as inherited topography might lead to erroneous results. Importantly, numerical fault-interaction modeling can help to better understand landscape evolution in active tectonic settings, especially in structurally complex environments with repeated reactivation of individual faults or fault arrays.

We used numerical fault-interaction modeling with different tectonic boundary conditions to calculate synoptic snapshots of artificial topography built by surface displacements due to the motions along the fault network. Motion along the faults was not pre-defined, but is a result of their orientation within the complex fault system and with respect to the applied regional stress field. We compared the resultant distribution of vertical displacements with topographic metrics from digital elevation models (DEM), such as topographic residuals (a measure of local relief and conditionally indicating high rock-uplift rates) and elevation, as well as with total displacement expressed by the exhumation history.

We have applied the modeling to the south-central Alborz mountains of Iran. The Alborz mountains constitute a high-relief landscape associated with low deformation rates and sparse seismicity, related to the ongoing Arabia-Eurasian collision. This region also yields a record of devastating historical earthquakes (M>7), which emphasizes the highly disparate nature of the spatiotemporal characteristics of tectonic activity in this intraplate setting. Furthermore, the complex tectonic history of this area, involving a changeover from dextral to sinistral transpression, has resulted in a composite tectonic landscape. The timing of this changeover is still subject to discussion due to the scarcity of chronologic information. Accordingly, the change in tectonic regime could have taken place either between 9 and 10 million years or during the Pleistocene.

We found close agreement between model results representing the present-day boundary conditions and the relief information from the DEM. This consistency between modeled results of one interaction cycle (corresponding to few earthquake events) and the mountain-scale landforms clearly shows that fault interaction in this sector of the south-central Alborz mountain is a long-term phenomenon. It also indicates that the landscape proxies for active tectonism can be largely explained by the present-day boundary conditions. The existence of inherited topography in the Alborz Mountains is possible along E-W striking faults. Such faults, however, are favorably oriented to accommodate NW- to NE-directed compression and are thus insensitive to reveal the kinematic change-over. On the other hand, these faults show the highest total displacement, as reflected by basement-involved faulting and exhumation, which might indicate sustained faulting under changing boundary conditions as suggested by the models.