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Mechanical restoration of large-scale folded multilayers using the finite element method: Application to the Zagros Simply Folded Belt, N-Iraq

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There are a large number of numerical finite element studies concerned with modeling the evolution of folded geological layers through time. This body of research includes many aspects of folding and many different approaches, such as two- and three-dimensional studies, single-layer folding, detachment folding, development of chevron folds, Newtonian, power-law viscous and more complex rheologies, influence of anisotropy, pure-shear, simple-shear and other boundary conditions and so forth. In recent years, studies of multilayer folding emerged, thanks to more advanced mesh generator software and increased computational power. Common to all of these studies is the fact that they consider a forward directed time evolution, as in nature.

Very few studies use the finite element method for reverse-time simulations. In such studies, folded geological layers are taken as initial conditions for the numerical simulation. The folding process is reversed by changing the signs of the boundary conditions that supposedly drove the folding process. In such studies, the geometry of the geological layers before the folding process is searched and the amount of shortening necessary for the final folded geometry can be calculated. In contrast to a kinematic or geometric fold restoration procedure, the described approach takes the mechanical behavior of the geological layers into account, such as rheology and the relative strength of the individual layers. This approach is therefore called mechanical restoration of folds.

In this study, the concept of mechanical restoration is applied to a two-dimensional 50km long NE-SW-cross-section through the Zagros Simply Folded Belt in Iraqi Kurdistan, NE from the city of Erbil. The Simply Folded Belt is dominated by gentle to open folding and faults are either absent or record only minor offset. Therefore, this region is ideal for testing the concept of mechanical restoration. The profile used is constructed from structural field measurements and digital elevation models using the dip-domain method for balancing the cross-section. The lithology consists of Cretaceous to Cenozoic sediments. Massive carbonate rock units act as the competent layers compared to the incompetent behavior of siltstone, claystone and marl layers.

We show the first results of the mechanical restoration of the Zagros cross-section and we discuss advantages and disadvantages, as well as some technical aspects of the applied method. First results indicate that a shortening of at least 50% was necessary to create the present-day folded cross-section. This value is higher than estimates of the amount of shortening solely based on kinematic or geometric restoration. One particular problem that is discussed is the presence of (unnaturally) sharp edges in a balanced cross-section produced using the dip-domain method, which need to be eliminated for mechanical restoration calculations to get reasonable results.