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The contribution of 3D restoration for the reconstruction of pre-thrusting basin geometries in fold-and-thrust belts

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The three-dimensional (3D) reconstruction of complex geological settings and of original, pre-thrusting basin geometry is one of the challenges for modern structural geology. It has indeed a critical role in many industrial applications, such as in the hydrocarbon exploration. By using commercial specific softwares to produce balanced cross-sections and inferred 3D reconstructions (2DMove™, Gocad™), we modelled a portion of the Umbria-Marche fold-and-thrust belt, in the outer zones of the Northern Apennines of Italy, in order to infer the pre-thrusting geometry of the Mesozoic-Cenozoic extensional basins and to test the applicability of existing computer tools in areas that have experienced the effects of positive tectonic inversion. In the study area, the accurate reconstruction of the structural setting, cross-cut relationships and timing of the deformation, was inferred by using field data, map analysis and cross-section balancing techniques. The structural overprinting relationships among the investigated thrusts made it possible to infer a general piggy-back thrusting sequence, with new thrust faults to the East, developed in the footwall of formerly emplaced thrust sheets, in the West. This allowed to sequentially remove the effects of the deformation for progressively older structures, and to back-strip the thrust sheets in sequential evolutionary steps, in order to reconstruct a viable pre-thrusting template. Four balanced cross-sections have been drawn, providing the initial skeleton for 3D modelling, together with the map trace of the major tectonic features. The cross-sections and the geological map have been digitized and geo-referred in 2D-Move™. Starting from the inferred geometries, a coherent 3D model was built in Gocad™. The surfaces represent post-thrust normal faults, thrust planes, and pre-thrust normal faults, and five key stratigraphic surfaces, from bottom; the base and top of the Calcare Massiccio fm. (Lower Liassic), the base of the Maiolica fm. (Titonian), the base and the top of the Marne a Fucoidi fm. (Upper Albian-Lower Cenomanian). The main pre-thrusting normal faults have been projected using their map and cross-section traces, keeping into account the thickness variation of the selected stratigraphic reference; the complete detail of the condensed and complete stratigraphic sequence was considered in cross-section only. The combination of balanced cross-sections, 3D modelling and restoration techniques, sequentially applied to fold-and-thrust belts, provides effective tools to unravel the geometry of the pre-thrusting geometries and depict the architecture of the sedimentary basins. Even if the surface restoration techniques are strongly dependant on the reconstructed surface geometry (i.e. the mesh of the surface and the obtained cutoffs along a fault surface), the results are comparable to the calculations obtained from classical 2D balancing techniques. The results of this work seem to encourage for further applicability of similar methods to other areas of the Northern Apennines, and to geologically complex areas in general.