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Fold evolution and the transition from folding to faulting: New insights from the carbonate multilayer succession of the Italian Eastern Southern Alps

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Understanding how folds and faults nucleate and grow is key to unravelling the tectonic and seismic evolution of both active and fossil fold-and-thrust belts (FATB). The progressive growth of folds and the transition from folding to faulting in FATBs are complex phenomena that reflect the combined effects of numerous deformation processes and boundary conditions. To better understand these complexities, we studied a folded sequence within the shortened Mesozoic carbonate multilayer succession of the seismically active Italian Eastern Southern Alps (ESA). The studied mesoscopic folds are parasitic to hanging- and footwall hectometric folds associated with regional-scale S-verging thrusts. We aimed to constrain (1) the folding style of the area, (2) the parameters governing the transition from folding to faulting through time, (3) the seismic vs. aseismic behaviour during the folding-faulting transition in carbonate-dominated fold-and-thrust belts, and (4) the overall tectonic framework of the ESA. Our approach relied on i) the structural analysis of symmetric and asymmetric folds and of the locally associated thrusts to assess the overall structural style and derive geometrical constraints upon the documented deformation features, ii) XRD analysis of the deformed carbonate multilayer to define its mineralogical composition and to establish the influence thereof upon deformation, and iii) mechanical modelling based on the Finite Element Method (FEM) to study the factors governing fold symmetry versus asymmetry.

Our field analysis shows that folds evolve from symmetric and open to south-verging asymmetric and close to tight before eventually being decapitated by discrete faults. This occurs once fold forelimbs exceed ~80°, which corresponds roughly with when the ratio between fore- and backlimbs dip angle exceeds ~3.3. The mesoscopic thrusts that dissect asymmetric folds firstly localise along the gently dipping backlimbs, exploiting clay-rich beds therein, and then propagate toward the foreland by cutting across the steep forelimbs, producing cataclastic domains. Layer-parallel shearing and cataclasis are the dominant deformation modes during thrusting along the backlimb and forelimb, respectively. FEM modelling, used to constrain the transition from symmetric to asymmetric folding, shows that it is mainly controlled by (i) the thickness and vertical

distribution of different rock types and (ii) the growth of first order folds at larger scales. In multilayer sequences we observe that small scale folds are initially symmetrical, forming under pure shear conditions. However, these structures may later become passively rotated in simple shear as they become parasitic to the growth of larger scale folds.

Finally, we propose a scenario of fold growth and transition from folding to faulting that has implications on the tectonic evolution of fold-and-thrust belts, including the coexistence of seismic and aseismic deformation during progressive shortening.