What steers deformation within fold-and-thrust belts: insights from the carbonate multilayer footwall of the Belluno Thrust, Italian eastern Southern Alps

Costantino Zuccari, Giulio Viola, Gianluca Vignaroli, and Luca Aldega

1 Alma Mater Studiorum, University of Bologna, Department of Biological, Geological and Environmental Sciences - BiGeA, Bologna, Italy (costantino.zuccari2@unibo.it)
2 Sapienza, University of Rome, Department of Earth Sciences, Rome, Italy

Despite significant recent progress in the understanding and quantification of the parameters controlling deformation modes in carbonate multilayers within fold-and-thrust belts, the details of early deformation and faulting during the initial stages of large-scale thrusting remain poorly documented and understood. Aiming to narrow this knowledge gap, we have chosen to study the relatively low-strain carbonate multilayer footwall of the Belluno Thrust (BT), one of the most external and S-vergent thrusts of the eastern Southern Alps (Italy). The BT footwall is composed of a c. 600 m thick Meso-Cenozoic multilayer succession of shallow water carbonate and pelagic sedimentary units characterized by strong mineralogical heterogeneity, with calcite (32-98%), sheet silicates (1-27%), and quartz (1-37%) as principal components. Its structural framework reflects cumulative strain due to multiple deformation events and is defined by the superposition of different structures such as i) south-verging asymmetric folds, ii) faulted folds, cut by slip planes with centimetric to metric throw, iii) SC-C' fabrics in the marly layers, and iv) cataclastic domains. Structures recording the early shortening increments are generally well preserved mesoscopic upright folds. Asymmetric folds with gently N-dipping backlimbs and steeply S-dipping (or even overturned N-dipping) forelimbs, record further shortening of the early upright and symmetrical folds. Strain is strongly partitioned within the marly layers, with discrete faults commonly defined by multiple slip surfaces forming duplex geometries and SC-C' fabrics and exploiting millimetric to centimetric marly beds as detachment layers. Thrusts and diffuse reverse faults not associated with any cataclasite localise along the backlimbs of the asymmetric folds, suggesting dominant layer-parallel shortening. Cataclasites develop instead along the thrust surfaces that cut across the steeply dipping (locally even overturned) forelimbs, where cataclastic flow becomes the dominant deformation mechanism. On the vertical forelimbs, cataclasis and strain localisation are commonly associated with veins, which contributed to harden the rock system.

Based on our systematic observations, we propose that deformation progressively evolved from folding and layer-parallel shortening (initial phases) to faulting and cataclasis (final phases) as a function of the dynamic interplay of the following factors: i) the geometrical relationships between fault orientation, fold attitude (forelimb and backlimb domains) and stress field, ii) the lithotype, which we conveniently account for by referring to the ratio between the cumulative thickness of
the outcrop marly layers and the total measured stratigraphic thickness, iii) the involvement of fluids during deformation, iv) the mineral assemblage of the involved layers and v) the geometric framework of the domain localising strain with respect to the principal stress axes orientation. We conclude that these parameters play a major role in guiding strain localisation and partitioning during continuous shortening within fold-and-thrust belts. They also govern the transition from overall aseismic creep to coseismic rupturing at the scale of mesoscopic structures and, possibly, of the entire belt.