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The Western Carpathians fold and thrust belt and its relationships with the inner zone of the orogen: constraints from sequentially restored, balanced cross-sections integrated with low-temperature thermochronometry

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The Western Carpathians are the northernmost, W-E–trending branch of a more than 1500 km long, curved orogen. Traditionally, the Western Carpathians have been divided into two distinct parts, namely the Inner Carpathians (including basement nappes) and the Outer Carpathians fold and thrust belt. These two major domains are separated by the so-called 'Pieniny Klippen Belt', a narrow zone of intensely deformed and sheared Mesozoic to Palaeogene rocks. In this contribution, a new interpretation for the tectonic evolution of the Western Carpathians is provided based on: (i) the analysis of the stratigraphy of the Mesozoic-Tertiary successions across the different orogenic domains; (ii) the construction of a series of balanced and restored cross-sections, validated by 2D forward modeling; and (iii) the integration of a large thermochronometric dataset (apatite fission tracks and apatite and zircon (U-Th-(Sm))/He ages). The latter work included thermo-kinematic modeling using FetKin, a finite element solver that takes as input a series of balanced cross-sections. The software solves the heat flow equations in 2D together with the predicted thermochronometric ages, which can be compared with the measured data. Moreover, the spatial distribution of burial depths, cooling ages and the rate of exhumation were correlated with heat flow, topographic relief, crustal and lithospheric thickness. This process allowed us to obtain the cooling history along each section and test the response of low-temperature thermochronometers to the changes in the thrust belt geometry produced by fault activity and topography evolution. Our sequentially restored, balanced cross-sections, showing a mix of thin-skinned thrusting and thick-skinned tectonic inversion involving the reactivation of pre-existing basement normal faults, effectively unravel the tectonic evolution of the thrust belt–foreland basin system. Our analysis provides a robust correlation of the stratigraphy from the Outer to the Inner Carpathians, independently of the occurrence of oceanic lithosphere in the area; it also allows for the reinterpretation of the tectonic relationships between the two major tectonic domains of the orogen, and the exhumation mechanisms affecting them. The interplay between thick- and thin-skinned thrusting had a relevant effect on the distribution of cooling ages. The non-homogeneous burial and exhumation history unravelled by our work suggests that different exhumation processes controlled the Neogene stages of the Carpathian evolution. In particular, the data point out a significant along-strike variation of exhumation mechanisms in the Outer Carpathian domain, ranging from Early Miocene syn-thrusting erosion to the west, to post-thrusting tectonic denudation in the central sector, to post-thrusting exhumation associated with uplift of the accretionary wedge to the east. Relatively young cooling ages (13 to 4 Ma) obtained for the Inner Carpathian domain were mainly associated with a later uplift, partly controlled by high-angle faulting, and coeval erosion. The effective integration of structural and thermochronometric methods carried out in this study provided, for the first time, a high-resolution thermo-kinematic model of the Western Carpathians from the Early Cretaceous onset of shortening to the present-day.