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Western alpine orogenic front geometry : new insight from the Digne nappe area by a 3D geometrical modelling approach

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The external parts of mountain belts, including their foreland basins, classically present a fold-and-thrust belt often detached on shallow decollement levels. These areas exhibit complex geometries with significant non-cylindrical components, necessitating a 3D approach to accurately determine the timing and style of deformation in the external zones.

The southwestern Alpine orogenic front is mainly characterized by the Digne Nappe, which thrusts over the deformed Mesozoic units. These Mesozoic units are unconformably overlain by the Cenozoic molasse deposits of the Valensole foreland basin, which are also deformed.

Despite the well-constrained sedimentary series of Barles and many of its structures, no study has yet fully explained the complex 3D geometries and processes that led to their formation. This region serves as an exceptional 3D example of a folded foreland, capturing much of the syn- and post-collisional history of the Alpine orogeny. The structural style, timing, and presence of salt structures remain challenging to specify, largely due to the non-cylindrical geometries that complicate simple 2D reconstruction. The Velodrome fold, formed by the initial deposits of the Valensole foreland basin, exemplifies a non-cylindrical structure whose understanding is still incomplete, leading to debates and various interpretations, including growth fold, post-sedimentary fold, and salt mini-basin.

To provide an accurate depiction and interpretation of the 3D geometries of the structures and to better characterize the style and timing of deformation in the Digne region, a combined approach of detailed structural field study and 3D geometric modeling using GeoModeller ©BRGM was undertaken. The 3D modeling was conducted at two scales: (i) regional, encompassing the Digne Nappe, the Robine unit, the Barles half-window, and the Valensole Basin, and (ii) more local, focusing on the Velodrome syncline. For the latter, GeoModeller was utilized to test hypotheses proposed in the literature. This approach enabled the reproduction of field-observed geometries in 3D, offering an interpretation of all formations consistent with surface observations. As a result, the contributions of regional tectonics and salt tectonics were assessed, and the timing of deformation was refined.

Elements of the geometry and timing of deformation in this frontal part of the Alps have been clarified. We show that south of the Barles half-window, the deformation of the Velodrome is early syn-depositional, starting earlier in the south of the basin (23 Ma) than in the north (18 Ma), requiring both regional tectonic control and halokinetic processes to account for the closure of the

folded structures. The northern part of this half-window shows more cylindrical structures, but some faults appear localized and correlated with thickness variations of the Tithonian unit, indicating a role of inheritance in the localization of deformation. Finally, this study also demonstrated the power of GeoModeller as a 3D tool that is both predictive and useful for testing geological hypotheses in areas as complex as folded forelands.