Long-term burial history and orogenic-scale fluid flow depicted from stable isotopes and stylolite paleopiezometry in the Umbria-Marches arcuate belt (Northern Apennines, Italy).

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Faults, joints and stylolites are ubiquitous features in fold-and-thrust belts, and have been used for decades to reconstruct the past fluid flow (or plumbing system) at the scale of folded reservoirs/basins. The textural and geochemical study of the minerals filling the fractures makes it possible to unravel the history of fluid flow in an orogen, when combined with a knowledge of the burial history and/or of the paleothermal gradient. In most cases, the latter derives from the former, itself often argued over, limiting the interpretations of past fluid temperatures. Yet, recent methodological developments applied to carbonates and calcite fillings provide new perspectives for a more accurate reconstruction of the temperature, pressure and timing of the fluids that were present in the strata at the time they deformed, at every stage of fold development. Indeed, the temperature at which fluids precipitated can be obtained by $\Delta^{47}$CO$_2$ clumped isotopes while the timing of calcite precipitation in veins and faults is given by U-Pb absolute dating. Also, the maximum burial depth of strata before contraction can be estimated using sedimentary stylolite paleopiezometry, hence in a way free of any consideration about the geothermal gradient.

These techniques were jointly applied at the scale of the Umbria-Marches arcuate belt (UMAR, Northern Apennines, Italy). Mesoscale faults and vein sets were measured and sampled in the Cretaceous-Eocene rocks. Focusing on those fractures that developed during Layer Parallel Shortening (LPS, i.e. oriented NE-SW to E-W) and during folding (i.e. oriented parallel to local fold axis), paleofluid sources, temperatures and timing were reconstructed using U-Pb absolute dating, $\Delta^{47}$CO$_2$ clumped isotopes as well as $\delta^{18}$O, $\delta^{13}$C, and $^{87/86}$Sr signatures of calcite veins. Results show a regional divide in the fluid system, with most of the belt including the foreland recording a fluid system involving basinal brines resulting at various degree from fluid-rock interactions (FRI).
between pristine marine fluids ($\delta^{18}O_{\text{fluid}} = 0\%$ SMOW) and surrounding limestones ($\delta^{18}O_{\text{fluid}} = 10\%$ SMOW). Precipitation temperatures (35°C to 75°C) appear consistent with the burial history unraveled by sedimentary stylolite roughness paleopiezometry (600 m to 1500 m in the range) and estimated geothermal gradient (23°C/km, Caricchi et al., 2004). As the degree of FRI increases forelandward, we propose a lateral, strata-bound, squeegee-type migration of fluids during folding and thrusting. In the western hinterland however, the fluid system rather involves hydrothermal fluids with a higher degree of FRI, the corresponding precipitation temperatures (100°C to 130°C) of which are inconsistent with local maximum burial (1500 m). As the Sr radiogenic signatures preclude any deep origin of the fluids, we propose that the fluid system prevailing in the hinterland during LPS reflects the eastward migration of formational fluids originating from the Tuscan basin, located west from the UMAR, where studied Cretaceous rocks were buried under more than 4 km of sediments during the Miocene.

Beyond being the first combination of paleofluid geochemistry and burial estimates through paleopiezometry, this fluid flow model illustrates how the large scale structures may control the fluid system at the scale of a mountain belt.