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Episodes of open fissure formation in the Alps

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Fluid assisted Alpine fissure-vein and cleft formation starts at prograde, peak or retrograde metamorphic conditions of 450–550 °C and 0.3–0.6 GPa and below. Early-formed fissures become overprinted by subsequent deformation, locally leading to a reorientation. Deformation that follows fissure formation initiates a cycle of dissolution, dissolution/reprecipitation or new growth of fissure minerals enclosing fluid inclusions. Although fissures in upper greenschist and amphibolite facies rocks predominantly form under retrograde metamorphic conditions, this work confirms that the carbon dioxide fluid zone correlates with regions of highest grade Alpine metamorphism, suggesting carbon dioxide production by prograde devolatilization reactions and rock-buffering of the fissure-filling fluid. For this reason, fluid composition zones systematically change in metamorphosed and exhumed nappe stacks from diagenetic to amphibolite facies metamorphic rocks from saline fluids dominated by higher hydrocarbons, methane, water and carbon dioxide. Open fissures are in most cases oriented roughly perpendicular to the foliation and lineation of the host rock. The type of fluid constrains the morphology of the very frequently crystallizing quartz crystals. Open fissures also form in association with more localized strike-slip faults and are oriented perpendicular to the faults. The combination of fissure orientation, fissure quartz fluid inclusion and fissure monazite-(Ce) (hereafter monazite) Th–Pb ages shows that fissure formation occurred episodically (1) during the Cretaceous (eo-Alpine) deformation cycle in association with exhumation of the Austroalpine Koralpe-Saualpe region (~ 90 Ma) and subsequent extensional movements in association with the formation of the Gosau basins (~ 90–70 Ma), (2) during rapid exhumation of high-pressure overprinted Briançonnais and Piemontais units (36–30 Ma), (3) during unroofing of the Tauern and Lepontine metamorphic domes, during emplacement and thrusting of the external Massifs (25–12 Ma; except Argentera) and due to local dextral strike-slip faulting in association with the opening of the Ligurian sea, and (4) during the development of a young, widespread network of ductile to brittle strike-slip faults (12–5 Ma).