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Linking megathrust earthquakes to faulting and mineral vein formation in a fossil accretionary complex

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Geodetic and seismological data recorded at active subduction zones suggest that megathrust earthquakes induce transient stress changes in the upper plate, which shift the wedge into an unstable state and trigger >Mw 6 aftershocks. These stress changes have, however, never been linked to geological structures that are preserved within fossil accretionary wedges, although plate interface of palaeo-subduction zones has been studied. The conditions under which accretionary wedges fail have therefore remained controversial. Here we show that faulting and associated vein formation in the palaeo-accretionary complex of the European Alps record stress changes generated by the subduction earthquake cycle. Our data integrate wedge deformation over millions of years but still demonstrate the dominance of specific fracture modes at different depths within the wedge. We trace the subduction of sediments by means of the 87Sr/86Sr isotope-systematics of mineral veins, which became more radiogenic at deeper levels. By combining our field observations and geochemical data with a dynamic Mohr-Coulomb wedge analysis, we show that early veins were formed in shallow levels by bedding-parallel shear during coseismic compression of the outer wedge. In contrast, later veins originated at deeper levels during normal faulting and extensional fracturing recording coseismic extension of the inner wedge. Our study shows how mineral veins can be used to reveal the dynamics of outer and inner wedges, which response in opposite ways to megathrust earthquakes by compressional and extensional faulting, respectively. We emphasise, that coseismic fracturing implicates an increase in permeability within the hanging wall of megathrusts. Understanding how fractures are generated throughout the subduction earthquake cycle is therefore essential to better contstrain the nature of postseismic fluid flow and to assess the seismic hazard of hydraulically driven aftershocks.