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Roadblocks and speed limits to volatile transport in active continental faults revealed by warm spring $^3He/^4He$ data patterns along the Denali fault, Alaska

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Helium and carbon isotopic data from 12 mineral springs along an ~400 km segment of the Denali fault system, Alaska, inform mantle-to-surface connections of this enigmatic structure. The Denali fault is a long-lived, >2000-km-long dextral strike-slip system that is presently active as evidenced by the M7.9 2002 Denali fault earthquake. Warm springs on the main strand, west of the 2002 earthquake rupture, have helium isotope ratios ($^3He/^4He$) up to 2.4 R_C/R_A (air-corrected $^3He/^4He$ relative to the air ratio, $R_A = 1.4 \times 10^{-6}$) indicating ~30% mantle He, assuming an asthenospheric origin. Corresponding carbon stable isotope ($d^{13}C$) values of dissolved CO_2 in these springs are -9.1 to -7.8 ‰ (VPDB), interpreted as partially mantle derived. At the eastern terminus of the 2002 rupture, Totschunda fault springs carry ~12% mantle helium, with $d^{13}C$ values (~0 ‰) derived from carbonates. A spring on the Hines Creek fault, a parallel and ancient structure to the north of the Denali fault, has ~20% mantle helium. Springs located along the 2002 rupture yield air-like $^3He/^4He$ (1 R/R_A) and $d^{13}C$ values from -9.2 to -3.4 ‰, interpreted as dominated by shallow groundwater circulation through shales and carbonates. A thrust splay parallel to the rupture zone has atmospheric $^3He/^4He$; whereas, an along-strike high-angle normal splay yields ~16% mantle He. Interpreted intersections of these splays with the main strand at <10 km and ~18 km, respectively, imply that deep flow paths along the ruptured strand are disrupted above ~10 km. Our results clarify questions about the lithosphere-scale nature of the Denali fault system, hydrologic connectivity of fault splays and the main strand, and possible hydrological impacts from the 2002 Denali earthquake. Because the Denali fault is a lithospheric scale, transcurrent structure separating North America from independently moving southern Alaska, we suggest that it has characteristics of a transform boundary. Based on comparisons with published $^3He/^4He$ data from other major strike slip faults and transform systems globally (e.g., San Andreas fault; North Anatolian fault system), we suggest that similarities in data patterns place constraints on the maximum mantle fluid flux into continental strike-slip faults in the absence of active magmatism.