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Microscale evidence of episodic fluid mixing and microbial activity in deep fracture systems of the Paradox basin, USA

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The deep biosphere of the upper few kilometers of Earth's crust hosts microbial communities that are important in the energy cycles of Earth. Although this environment can be considered relatively stagnant compared to surficial environments, changes in habitability due to burial and denudation, fracture reactivations, and water infiltration events can be envisioned, but the effects of such events remain elusive and underexplored. Here we show isotopic evidence for microbial colonization of deep fracture networks of the Permian Paradox basin, USA, in relation to low-temperature fluid infiltration events that succeed inhabitable burial of the studied crustal volume. We studied three subareas and our microscale isotope analysis, clumped isotope thermometry and radioisotopic geochronology elucidated late Cenozoic events of low temperature meteoric water infiltration related to incision of the Colorado River, as well as the Dolores River, altering topographic gradients and meteoric fluxes. This sparked methanogenesis and biodegradation of indigenous hydrocarbons, such as bitumen. The latter is also indicated by biomarker analysis. Earlier mineral precipitation events recorded in several U-Pb age clusters over a timeframe of hundreds of millions of years featured higher formation temperatures and mark episodic reactivation of the fracture systems driven by far-field tectonics, extension, burial and uplift-cycles. Our microscale approach gives new insights into the episodic shifts in habitability and microbial metabolisms in the deep biosphere, in relation to large-scale hydrological, hydrochemical and burial/uplift cycles.