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Thorium in river water reveals bedrock fracture processes triggered by distant seismic events

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Fractures in bedrock supporting the critical zone enable the release of geogenic elements that enter biogeochemical cycles and that impact the chemistry of rivers in catchments and downstream hydrologic systems. Although fractures are integral to the geochemistry and hydrology of watersheds our understanding of fracture dynamics is very limited because of the challenge of detecting changes in the subsurface. Seismic monitoring is sensitive to motions on faults, including earthquakes that can change flow pathways, permeability and groundwater chemistry. However, near-surface bedrock everywhere is fractured, through processes presently not detected through seismic monitoring. River and groundwater chemistry is highly affected by water-rock interactions but chemical signatures of aseismic fracture processes have not been identified in major solute concentrations due to their complex temporal structure caused by myriad biogeochemical, meteorological and other factors. Here we show that long-term, high-frequency measurements of the river concentration of the ultra-trace element thorium (Th) can provide a novel signature of bedrock fracture processes spanning neighboring watersheds in Colorado. Patterns in Th excursions and seismicity strongly suggest that the formation or motion of stressed, high-permeability fractures can be initiated by ground motion caused by distant seismic events. This finding is the first chemical signature of dynamic earthquake triggering, a phenomenon previously identified only through geophysical methods. The use of high-frequency elemental data will complement emerging geophysical methods to reveal the architecture, dynamics and impact of the deep fracture hydrology of the critical zone.