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The Hidden Hydrogeosphere

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The canonical water cycle assumes that all water entering the subsurface to form groundwater eventually re-enters the surface water cycle. Recent discoveries have challenged that model, with investigations of groundwater provenance and residence times demonstrating fluids stored in isolation from the modern water cycle on scales of hundreds of millions to more than a billion years (1-2). Here we introduce a new conceptual framework that includes the large volume of water estimated to globally account for 30-46% of the planet's groundwater, but that is typically overlooked by traditional water cycle models. This highlights a fundamental gap in our understanding of the water cycle on a planetary scale, including characterizing recharge, mixing between deep and more near surface aquifers, and fluid contributions from water-rock reactions, fluid inclusions or hydrothermal fluids (1). This immense "Hidden Hydrogeosphere" is fundamental to society's energy, resource and climate challenges as this it is where new resources of helium, hydrogen and other elements critical to the green energy transition are found; is a target for geologic repositories for nuclear waste, and for carbon sequestration; and hosts the deep subsurface biosphere, estimated to account for a significant proportion of the Earth's biomass (1).

Recent discoveries in groundwater and fluid dating have transformed our approach to deciphering physico-chemical processes preserved in geofluids (2-4). Science has long relied on fluid inclusions to access preserved samples of ore-forming fluids, metamorphic fluids, and remnants of the ancient atmosphere and hydrosphere. Until recently, groundwaters were thought to reflect only much younger periods of water-rock interaction (WRI) and Earth history, due to pervasive recharge from the surface. By moving beyond mean groundwater ages to additionally constrain the "oldest drop", and "youngest drop", reveal that not only do these groundwaters provide opportunities for investigation of the Earth's ancient hydrosphere and atmosphere, but they open up new lines of exploration of the history and biodiversity of extant life in the Earth's subsurface (1).

1. Sherwood Lollar et al., 2024 AREPS 52:15.1-15.24.
2. Warr et al., 2022 Nature Comm. 13:3768.
3. Holland et al., 2013 Nature 497:357-360.
4. Warr et al., 2023 GCA 348:221-238.