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Regional Tectonic Influence on Groundwater Recharge, Age, and Climate in Arabian Peninsula

FAHAD SOUID[1], DARREN HILLEGONDS[1], SATTAM MUTAIRI[2], EKATERINA KAZAK[2], ABDULLAZIZ GAOUD[2], ORFAN SHOUAKAR-STASH[3] AND CHRIS J. BALLENTINE[1]

[1]University of Oxford
[2]Aramco
[3]University of Guelph

Identifying groundwater age in sedimentary basins is essential for aquifer protection and sustainability, economic resources assessment, and understanding the role of regional plate tectonics on groundwater recharge. Helium accumulation in groundwater can be used to date mean groundwater residence ages from thousands to hundreds of millions of years; but is sensitive to both basal helium flux and diffusive loss-to-surface. In arid regions, groundwater is too old to be dated by radiocarbon. Here we show how regional plate tectonism influences regional groundwater age using helium diffusion profiles calibrated with dissolved ^{4}He concentrations from different basins and aquifers in Saudi Arabia.

Helium diffusion models from the crystalline basement to the surface were constructed for two basins in the Arabian Peninsula: The Northwestern and Jafurah Basins. Groundwater ^{4}He concentrations (n=66) have been determined in fluids from different formations within the sedimentary succession of the two basins. Observed ^{14}C activity in the shallower aquifers shows continued episodic recharge, with $\delta^{18}O$ and δD indicating a transition from Mediterranean to continental type recharge. This is consistent with continental changes in Pliocene and Pleistocene weather patterns, with humid intervals becoming shorter and less intense across the Arabian Peninsula. Such limited recharge in the shallower aquifers is reflected in the observed mixing of both old (helium bearing) and younger (^{14}C active) sources.

In distinct contrast, diffusion models gave a common groundwater age of 5.0 ± 0.5 Ma for the deeper aquifers in both basins. This aligns with deep aquifer closure to significant recharge across the Arabian Peninsula concurrent with closure of the Tethys and subsequent desiccation of the Mediterranean and Red Sea (Messinian Salinity Crisis) between 6.2 and 5.3 Ma. This is consistent with the Red Sea seafloor spreading tectonism and uplifting; disrupting deeper flowpaths across the shield, likely by faulting causing outflow pinchout or increased pore-pressure from intensified erosion and sedimentation, preventing effective deep recharge. Similar tectonic impacts elsewhere likely allow to identify preservation of similar, or yet older, deep groundwater systems.