Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.38079

The role of diffusion in determining geological helium resource potential on multiple spatial and temporal scales

CHRIS J. BALLENTINE[1], DARREN HILLEGONDS[1], DALAL SAEED[1], THOMAS D RENSHAW[1], FAHAD SOUID[2], EDWARD BLACKMAN[1], RED COLEMAN[1] AND MOHAMMED ALSHAREEF[2]

[1]University of Oxford

[2]Dept Earth Sciences, University of Oxford, UK

The mean residence age of groundwater gauges hydrogeological stability. On timescales relevant to oil, gas, helium and hydrogen accumulation, fluid age commonly exceeds cosmogenic dating limits (^{14}C, ^{81}Kr). Radiogenic ^{4}He production from U+Th extends dating from ka to Ga; in low-permeability systems ^{4}He approximates a closed system and fluid age can be estimated from local U+Th, ^{4}He and porosity [1]. Some sedimentary aquifers show ^{4}He concentrations requiring an additional regional basal ^{4}He flux into sequences capped by low-permeability layers [2]. Simple "capped" fluid ages neglect diffusive loss to the surface and require poorly constrained flux estimates. A 1D diffusion model tied to basin model stratigraphic thickness and porosity evolution resolves basal ^{4}He flux and considers the 1D column context as linked near-closed, capped, and open components (basal-flux, in-situ, flux-out terms), according to the architecture of each basin system [3]. Applied to the Jafura and Northwestern Saudi Peninsula basins, this approach yields a common deep-aquifer ^{4}He age of 5.0 ± 0.5 Ma, consistent with aquifer closure during Tethys closure and Messinian desiccation [4]. Old groundwaters also concentrate ^{4}He-bearing gases (e.g., N_2), which can exsolve as ^{4}He-rich gas phases that migrate and accumulate by buoyancy [5]; calibration in the Williston Basin, Canada, emphasizes the importance of trap drainage for resource formation [6]. Within the crystalline basement, ^{4}He partitions between porewater and the mineral lattice; the mineral Helium Accessible Volume (HAV) is in diffusive equilibrium with the porefluids and must be quantified to obtain accurate fluid ages. While fluid-age determinations in crystalline basement source rocks are now possible [7], incorporating HAV partitioning into expulsion and migration models remains a key challenge for quantifying helium transfer from basement source rocks into into shallow sedimentary reservoirs.

[1] Holland et al., (2013) Nature 497, 357;
[2] Torgersen and Clarke (1985) GCA 49, 2445;
[3] Cheng et al., (2021) EPSL 574, 117175;
[4] Souid et al., (2026) Goldschmidt abstract;
[5] Cheng et al., (2023) Nature 615, 94;
[6] Renshaw et al., (2026) Submitted;
[7] Saeed et al (2026) Goldschmidt abstract;