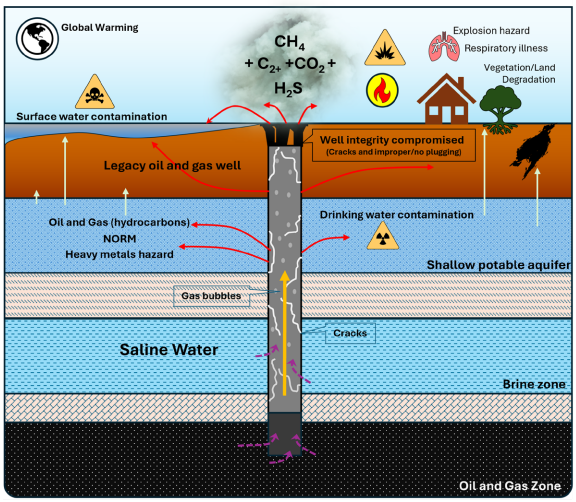
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A Hydrogeochemical and Stable Isotope Study for Assessing Fluid Migration and Origin in Northwestern Appalachian Basin's Abandoned Oil and Gas Wells

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Abandoned oil and gas wells create long-term subsurface connectivity that can potentially facilitate the migration of methane and saline formation waters into groundwater and surface ecosystems, compromising the integrity of shallow aquifers and atmospheric chemistry (Figure 1). This legacy oil and gas infrastructure is spread across North America (>4 million in the USA and > 320,000 in Canada), including the Northwest Appalachian Basin in Pennsylvania (USA), the emphasis of this study, and the location of the oldest commercial oil wells in the world.

This study aims to understand the origin, migration, and mixing of fluids sampled from abandoned wells by integrating major-ion geochemistry (Cl, Na, SO_4, Br, Ca, etc.), stable water isotopes ($\delta^{18}O$, $\delta^{2}H$), bulk gas composition, $\delta^{13}C$–$\delta^{2}H$ isotopic ratios, as well as noble gas and clumped isotopes. The preliminary results show (i) expelled water is mostly of meteoric in origin, as most of the samples plot predominantly on the Local Meteoric Water Line, however; (ii) moderate chemical variability (chloride levels ranging from <1 mg/L to 4000 mg/L), which may be indicative of modest mobilisation and mixing of deeper brines with meteoric groundwater (using ion cross-plots such as Cl vs. Na, Cl vs. Br, Cl vs. $\delta^{18}O$); (iii) potential upward migration of hydrocarbons, as suggested by their elevated concentrations identified through bulk gas analysis; and (iv) this migration facilitating potential microbial addition and overprinting of initial thermogenic hydrocarbons (methane) by microbial processes in most of the wells evidenced by the isotopic signatures.

Forthcoming noble gas and clumped isotopic data will provide a clear, deeper insight into the fluid provenance and mixing, temperature history, as well as the dynamics surrounding the abandoned oil and gas wells. This research underscores the necessity for systematic geochemical monitoring and robust well-integrity assessments in historically developed hydrocarbon fields, where improperly managed wells can pose persistent environmental risks.