Geochemical Modeling of Fluid Convection and Hydrothermal Alteration in Sub-Salt Layers of the Northern Red Sea Basin

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ABSTRACT

Previous studies on hydrothermal activity in the Red Sea Basin were principally focused on hydrochemical and mineralogical characteristics of deep sea brine pools along the axis of the Red Sea spreading center and the geochemical composition of interstitial pore fluids from shallow sediment core material. Little is known about the abundance and provenance of sub-sea and sub-salt fluids and the potential existence of deep circulating hydrothermal regimes. For the first time in the northern Red Sea basin, deep formation water from Late Cretaceous (Adaffa Formation) and Lower Miocene (Al Wajh Formation) sedimentary units were recovered from offshore exploration wells and fingerprinted on their geochemical (major elements, trace elements) and multi-isotopic composition (δ2H, δ13C, δ18O, δ11B, 36Cl/Cl, δ37Cl, δ81Br, 87Sr/86Sr). Petrographic and mineralogical fingerprints from drilling cores and cuttings were correlated with geochemical evidence of secondary fluid alteration to quantify type and position of hydrothermal zoning. The 14C-radiometric age dating of deep groundwater revealed the presence of an extreme dynamic hydraulic system with infiltration of surface water into sub-salt units during the Late Pleistocene to Middle Holocene, probably related to low sea level stands during the Last Glacial Maximum. Basin bounding faults and conglomerates act as fluid conduits for ground water penetration and potential reservoir flushing. 87Sr/86Sr ratios of 0.707307 to 0.707350 for hypersaline brines suggest convective fluid circulation occurred from Late Miocene–Cretaceous strata into the underlying igneous basement, with a ~30% contribution of strontium from 87Sr/86Sr-depleted basalts. The fluid deficit in sodium and excess in calcium, combined with the lack of in-situ plagioclase in the Al Wajh Formation and the presence of altered feldspar in the igneous basement, point toward albitization of the basement as major fluid-rock alteration process. Local geochemical similarities between inter-stratigraphic units suggest hydraulic connectivity between specific wells for the Al Wajh horizon, which could imply lateral reservoir continuity for potential hydrocarbon migration. Hydrostatic water-wet sands beneath stratigraphic top seals imply the presence of lateral fluid migration. The interpretation of the regional magnitude of flow migration is still limited by a restricted number of available samples from exploration wells.