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Origin of formation water from the Unayzah and Khuff petroleum reservoirs, Saudi Arabia

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Abstract

Chemical and isotopic fingerprinting techniques provide support for tracing the origin and evolution of formation waters taken during downhole and drill stem tests from exploration wells in Saudi Arabian oil and gas fields. Low molar Cl/Br ratios (85-93) and a $\delta^{18}O$ reverse loop suggests an evaporative seawater origin for hypersaline water from the Upper Permian-Lower Triassic Khuff Formation. In contrast, formation water from the Upper Carboniferous-Lower Permian Unayzah Group shows a heterogeneous trend between low salinity/low $\delta^{18}O$ freshwater and hypersaline/intermediate $\delta^{18}O$ brine, the latter being a product of evaporated seawater. Unayzah water salinity increases linearly with depth at the rate of 77 to 98 mg/L per meter, allowing quantitative prediction of water resistivity (R_w) at specific reservoir depths. The increase in Ca and depletion of Mg and HCO_3 with Unayzah depth suggests the impact of temperature-triggered ion exchange processes that alter the primary host rock and formation water composition.

Keyword: Saudi Arabian petroleum reservoir; formation water; Unyazah; Khuff formation; hydrochemistry; groundwater evolution.

1. Introduction

Water data from producing wells can contribute to an improved understanding of reservoir connectivity and provide assistance with water production problems in oil and gas fields. Of particular interest is the ability to fingerprint waters from different reservoirs to remediate future water encroachment. For the case of oil and gas reservoirs in Saudi Arabia, geochemical approaches to determine the origin of produced water are still in their initial stages for the purpose of reservoir characterization. Previous studies [1] revealed the common presence of paleo-groundwater recharged in the late Pleistocene under a

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climate that was cooler and more humid than the present. The present study compiles chemical and isotopic analytical data from produced water in exploration wells, in order to interpret the geochemical evolution and spatial distribution of deep groundwater in Unayzah B and C gas reservoirs (late Carboniferous to early Permian in age), Unayzah A oil and gas reservoirs (early Permian age), and Khuff gas reservoirs (late Permian to early Triassic age).

2. Geological setting

The Upper Carboniferous to Lower Permian, siliciclastic Unayzah Group in Saudi Arabia forms part of the pre-Khuff Paleozic succession, with a subdivision into the glaciogenic Juwayl Formation overlain by postglacial deposits of the Nuayyim Formation. Glacial-fluvial outwash sandstones at the lowermost unit of the Juwayl Formation contains the gas-bearing Unayzah C Reservoir, directly overlain by siliciclastic glacio-lacustrine rocks from the gas-bearing Unayzah B reservoir, and the siliciclastic mix of the oil- and gas-bearing Unayzah A reservoir [2, 3]. The opening of the Neotethys initiated the deposition of marine sediments during the late Permian, forming a broad shallow carbonate platform over much of central and eastern Saudi Arabia. The Middle Permian Basal Khuff Clastics are overlain by an Upper Permian to Lower Triassic sequence of five shallow to intertidal carbonate and evaporite units. The Khuff carbonate intervals comprise gas reservoirs throughout much of eastern Arabia, while their interlayered evaporite units provide excellent seals [3].

3. Methods

A total of 18 samples of produced water were recovered from exploration wells from Unayzah and Khuff reservoirs in Saudi Arabia during the time period from April 2007 to January 2011. Chemical analyses were performed in the *Chemistry Analysis Unit* (R&DC) and stable isotopes in the *Geochemistry Unit* (EXPEC-ARC) in Dhahran, Saudi Arabia. As produced water from exploration wells is commonly affected by production-related fluids, several chemical parameters (e.g. K/Cl ratio, pH, ion balance) and geothermometers (in concordance to measured reservoir temperatures) were applied to select representative samples of uncontaminated formation water.

4. Results

4.1. Origin of Unayzah and Khuff groundwater

The origin of salinity in fluids from sedimentary basins has historically been attributed to subaerial evaporation of seawater, salt dissolution, and/or shale membrane filtration. In the case of hypersaline water samples (TDS_{max} = 343,000 mg/L) from Unayzah and Khuff gas reservoirs, extreme subaerial evaporation of seawater with low molar Cl/Br ratios (85 - 141) approached epsomite and sylvite oversaturation, respectively, of bittern water. Hypersaline water samples from the Khuff reservoir are enriched in ^{18}O ($\delta^{18}O$ = 3.6 to 6.5‰) and salinity (TDS ~280,000 mg/L), which indicates strong WRI processes causing a positive ^{18}O-shift in the fluid phase (and a correlated ^{18}O depletion for the host rock), or "super-evaporation" of seawater with a typical isotopic reversal loop during extreme evaporation. Its location close to the Seawater Evaporation Trajectory (*SET)* with a low molar Cl/Br ratio (85-93) supports the hypothesis for the dominance of evaporative seawater. In contrast, brackish to intermediate saline water (TDS = 7,300 - 135,100 mg/L) from the Unayzah Formation is close to the present Global Meteoric Water Line (*GMWL)*, which suggests meteoric water as the primary component of groundwater (Fig. 1). Extremely depleted $\delta^{18}O$ and $\delta^{2}H$ ratios for some samples indicate infiltration of paleo-meteoric