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An Overview Study on the Origin, Occurrence, and Modeling of Sand Injectites in the Bahrah Area, Northern Kuwait Bay

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Abstract

As an overview study, this work presented for the first time a multidisciplinary quantitative and qualitative investigation linking surface and subsurface geology to explain the origin and formation mechanisms of enigmatic sand injectite outcrops at two sites in the Bahrah coastal plain, northern Kuwait Bay. The study integrated field observations, aerial photography, petrography, isotope geochemistry, fluid-inclusion microthermometry, and 3D seismic interpretation to develop a comprehensive understanding of the geological (Al-Hajeri et al., 2020; Al-Hajeri et al., 2021) and fluid-dynamic processes responsible for these features (Marchelli et al., 2022).

Field mapping and stratigraphic analysis revealed complex injection architectures composed of reworked fine- to medium-grained sands intruding overlying mudstones. Thirty-one rock samples were analyzed for petrography, fluid inclusions, and strontium isotopes to constrain fluid origin and diagenetic evolution. Microthermometric and isotopic data indicated that the injectites formed through a near-surface, focused fluid-injection system driven by the interaction of hydrocarbons, seawater, and groundwater.

A five-episode conceptual model was proposed: (1) development of a shallow geobody—likely a paleoshoreline—sealed by shale; (2) up-dip lateral hydrocarbon migration and entrapment with seawater–groundwater mixing; (3) biodegradation of trapped hydrocarbons generating CH_4, CO_2, and H_2S gases; (4) overpressure buildup resulting in non-tectonic forced folds and polygonal to semi-circular fractures; and (5) overpressure release—possibly triggered by seismic activity—causing rapid gas–water–sand remobilization through weakened fracture zones to form pipes and sinuous injectites.

Fluid-dynamics modeling supported the proposed mechanism by reproducing the main injection geometries and highlighting the role of pressure, permeability, and sediment properties in sand mobilization.

The integrated geological, geochemical, and modeling results demonstrated that the Bahrah sand injectites are surface manifestations of subsurface fluid overpressure and biodegradation processes within a dynamic groundwater–seawater mixing environment. This overview study established a foundational model for the genesis of sand injectites in northern Kuwait Bay and emphasized the added value of fluid-dynamics modeling in understanding shallow subsurface sediment mobilization.

From a field-development perspective, sand injectites have significant implications for oil production efficiency and reservoir continuity. Acting as high-permeability thief pathways, these features can divert injected fluids away from target zones, reducing sweep efficiency and causing early water or steam breakthrough. Their irregular geometries and variable permeability may compartmentalize reservoirs, creating anisotropic flow patterns that disrupt lateral continuity and complicate pressure support. In enhanced recovery operations, injectites can further degrade injectivity and conformance by promoting unplanned crossflow between layers or reservoir compartments.

Recognizing and predicting the distribution of these injectite corridors is therefore essential for effective reservoir management. Integrating seismic attributes and geomorphological indicators enables early risk screening prior to drilling, while accurate mapping supports optimized well placement—either to avoid thief zones or to strategically intersect high-deliverability conduits when advantageous. A thorough understanding of injectite behavior also guides the design of tailored sand-control and corrosion-mitigation strategies and the implementation of dynamic monitoring programs using pressure, tracer, and saturation data to manage compartmentalization. Overall, accounting for the presence of sand injectites delivers direct economic value by improving recovery factors, reducing injectant losses, enhancing reservoir connectivity, and increasing the reliability of future field development forecasts.

References

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