The Velkerri Conundrum: How Long Can Hydrocarbons be Retained in a Shale?

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ABSTRACT

Unconventional shale reservoirs are widely regarded as closed systems with very low matrix porosity and permeability. Upon burial and subsequent thermal maturation, most of the hydrocarbons (HCs) generated from these systems are assumed to be retained within organic matter- or mineral-hosted pores. This raises the question of the differences between shale units acting as an unconventional shale reservoir, a source rock in which expulsion is implicit and a seal with similar permeability ranges in which migration is not possible. This tension is illustrated in the l.4Ga Velkerri Formation, within the McArthur Basin (Australia) that is arguably considered as the oldest known petroleum system in the world. The present estimates are that hydrocarbons have been generated from the Velkerri Formation prior to I Ga, in response to sill intrusion and structural inversion events in the McArthur Basin. Permeability is deemed negligible and a significant proportion of the generated HCs is thought to be retained within the Velkerri Formation sediments. This challenges our perceptions of potential HC retention mechanisms and how negligible permeabilities can support HC retention over the course of hundreds of millions of years. Yet, "live oil", abundant solid bitumen and oil shows provide strong evidence of active HC migration pathways.

The Velkerri Formation is a potential unconventional system of particular interest due to its significant petroleum potential and relatively moderate thermal maturity with respect to the oil window. This formation includes organic-rich fine-grained sediments with total organic carbon content ranging from I to 3% and commonly exceeding 5%. At the Urapunga-4 core location, the Velkerri Formation is comprised predominantly of millimetric-scale alternations of dark organic-matter of likely microbial mat origin and siltstone laminae as well as subordinate very fine-grained sandstone. Rock-Eval pyrolysis data and microscope imaging show the co-occurrence of marginally thermally mature organic matter as well as migrated oil and bitumen. Rhenium-Osmium (Re-Os) isotopic data of the middle Velkerri Formation in Urapunga-4 core define two distinct isochrons; one Re-Os isotope population yields an age of I4I7 Ma that is consistent with U-Pb zircon age from underlying tuff beds (I492Ma). The second Re-Os regression isochron, however, yields a significantly younger age of 400Ma. We interpret this young age to likely reflect mixing and homogenization processes during a late phase hydrocarbon generation and migration in response to Devonian tectonic events associated with the Alice Springs orogeny. These observations, in agreement with petrographic data, suggest that the Velkerri Formation is not a closed system. While the organic matter within the Velkerri Formation is of great antiquity (I.4Ga), the system shows more conventional source-like properties with late stage of HC generation and migration and significant remaining HC potential. HC retention in this particular unconventional shale system is a function of thermal maturity and the bitumen associated with marginally mature organic matter likely migrated from deeper parts of the basin at 400Ma.