Tectonic Signatures in Sandstone Compaction Curves from Western North America: Implications for Porosity Prediction in Frontier Basins

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Predictive tools for subsurface rock properties, such as porosity, are critical for hydrocarbon exploration in frontier basins and for planning geologic carbon sequestration projects in saline aquifers. Key processes that govern sandstone porosity during burial through geologic time include mechanical compaction, pressure solution, cementation, and possibly other chemical reactions, such as mineral dissolution and alteration. Commonly, burial depth is used as a proxy for a suite of geologic variables that drive these processes. To a first approximation, sandstones in basins from around the world exhibit a diverse range of exponential decline curves relating porosity to increasing burial depth. However, existing analog databases of porosity versus burial depth tend to group data by age and neglect the tectonic setting of a sedimentary basin, possibly obscuring trends that are specific to certain basin types.

Herein, we exploit a proprietary petroleum production database, published by Nehring Associates, which contains 3580 measurements of average porosity for sandstone petroleum reservoirs in western North American basins. Porosity measurements in each basin extend from near the surface to current burial depths of 3-5 km. The basins span a number of different tectonic settings, and for each basin, we fit exponential compaction curves in order to explore the importance of the tectonic setting of a basin. We show that basins characterized by similar rates of tectonic subsidence, but sourced by disparate geologic terranes, including volcanic arcs, recycled sedimentary deposits, and crystalline basement rocks, exhibit a range of compaction curves. In basins characterized by lithic-rich sandstones, porosity decays rapidly with increasing burial depth relative to basins characterized by more quartz-rich sandstones. We also show that slowly subsiding passive margins appear to experience a relatively small reduction in porosity at a given burial depth relative to basins with a rapid component of tectonic subsidence. It appears that variations in sandstone composition, which is in turn influenced by tectonic setting, may set the relative importance of various diagenetic mechanisms. We attribute the relatively small reductions in porosity during slow burial to a) the temperature dependence of quartz cement precipitation, and to b) the prolonged formation of other cements such as carbonate and clay at shallow depths. Shallow cementation preserves porosity by stabilizing framework grains and inhibiting compaction. Although tectonic signatures in compaction curves appear to be subtle and superimposed by many competing mechanisms that influence porosity, the tectonic setting of a basin may facilitate first-order predictions about subsurface rock properties in frontier basins for hydrocarbon exploration and CO_2 sequestration.