Shale Natural Resources

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The development of shale natural resources has had a sudden and dramatic effect on the US and Canadian economies. The oil and gas upstream community has successfully developed this methodology as a result of a methodical series of engineering, chemical, and technological innovations applied with entrepreneurial spirit. The sustainable success of shale development is a four-fold mechanism comprising geology/geography, technology, infrastructure, and political/social elements. This paper focuses on these four aspects associated with shale resources for natural gas and liquids rich producing assets, discussing the circumstances and technologies that have delivered the current state of events.

Shale natural resources are global in nature, with pockets of successful activity, opportunity, and exploration occurring in various locations. North American development is currently the most active, but developing opportunities exist within Saudi Arabia, Argentina, Australia, China, and Russia. While many other locations have potential, barriers to economic production are present across this broad spectrum of geographies, which is why many believe the North American environment will continue in the near and medium term to sustain the highest level of development.

The technologies necessary to develop the shale opportunities are spread across many science and engineering domains, which are broadly described here, along with other requirements and opportunities. Infrastructure requirements can be simple or complicated, and a review of the full-cycle infrastructure illustrates possible barriers to economic development, in terms of both servicing the construction of the wellbore assets and producing the hydrocarbon itself.

Section 1: Geology/Geography

The single most important factor for developing a shale asset is the existence of subsurface conditions that promote the creation of hydrocarbons within a rock structure that is conducive to positive economic flow rates. There are a vast number of reservoir attributes that are crucial to reducing the uncertainty of economic productive capacity. First is the geological structure, meaning the overarching circumstances that manifest a large-bodied formation system of substantial hydrocarbon reserves, normally with high organic content. Over a geological period of time (pressure and temperature), surface matter is buried and begins the process of diagenesis. Diagenesis is a transformative process that converts organic matter to hydrocarbons, of differing carbon chain lengths, existing in the subsurface, and subject to migration or transportation under the correct circumstances.

A leading indicator of quality shale reservoirs, measured early in the exploration phase, is total organic content, or TOC. This measurement indicates to the geoscientists that the potential for hydrocarbon exists. In the most normal form, TOC is measured as the percentage of kerogen, a mixture of organic chemical compounds that makes up a portion of the organic matter in sedimentary rocks. Kerogen has a number of interesting properties, such as variable density, porosity, etc., so while this property of shale is important, it can be misleading for development purposes. Rickman et al. (2008) describe the standard industry approach for using and interpreting subsurface data for the application of hydraulic fracturing of shale reservoirs.

Other properties, such as permeability and porosity, are very normal measurements that are important to the economic development of any reservoir. These also include geomechanical properties, such as Young's modulus and Poisson's ratio, geochemical properties, such as clay, quartz, or carbonate content, and finally reservoir properties, such as temperature and pressure. There are, of course, many hundreds of other important subsurface properties, attributes, and considerations, and careers are built within the petrophysical, geological, geophysical domains around their study to determine what those important attributes are and how they impact the reducibility of these reservoirs.

The reservoir properties combined are important to geoscientists and engineers for three reasons:

- Reserves estimations
- Engineering (drilling and completion)
- Surface impacts

There is no clear definition for shale or even what makes a reservoir unconventional. The terms "shale" and "unconventional" are somewhat interchangeable within the current industry in the macro business environment. The majority of industry professionals identify permeability as the key formational attribute that distinguishes an unconventional formation from a conventional one. But with time, even this will become indistinguishable. Some classify "unconventional" as any formation that requires hydraulic fracturing to establish economic production rates.

Shale is classically defined as a fine-grained, clastic sedimentary rock composed of mud that is a mix of flakes of clay minerals and tiny fragments (silt-sized particles) of other minerals, especially quartz and calcite. The "fine-grained" component of that definition infers a low-permeability and low-porosity structure. These attributes can lead to uneconomic flow rates under natural conditions; thus, the justification for use of hydraulic fracturing and the lack of specific terminology. Sondergeld et al. (2010) is an excellent reference for this domain.

Section 2: Technology

The technologies necessary to develop unconventional natural resources are broad and exist across many domains. Key technologies, such as surface seismic, downhole micro seismic, fiber optics, rock and fluid sampling, and sensor physics, are used currently to better define the reservoir. Added to this are data integration, visualization, and large data management.

Drilling technologies that are important include top-drive flexible drilling rigs, automated pressure-while-drilling control systems, downhole rotary steerable systems, drillbit design advances, fluid chemistry, telemetry systems (mud pulse technology for data delivery), and advancements to mud motor systems. These technologies enable a greater number of horizontal wellbores to be drilled faster, safer, and longer.

Completions technologies that are significant for unconventional development include hydraulic fracturing, fluid chemistry (specifically, clay control, complex nano-fluids "surfactant family," and bacteria control), surface equipment design, fueling advancements, and flow-through porous media design.

Presently, a popular technology used in unconventional reservoirs is seismic interpretation advancements and the data integration of those advancements into drilling and completion operations. As the unconventional industry has matured, the technology focus and usage has also evolved. In the 1970s, 80s, and 90s, the use of hydraulic fracturing in low-permeability, low-porosity tight reservoirs was commonplace in vertical wells across the US and abroad. After more research on fracturing applications in horizontal wellbore configurations, horizontal drilling techniques were adopted in the 2000s and continue through the present day. The combination of these two technologies created the explosion of successful economics observed to date.

King (2010) began observing and visualizing seismic attributes with hydraulic fractures in horizontal wells, typically in combination with downhole micro-seismic data acquisition. Since that time, the industry has evaluated and interpreted seismic data sets and made advancements in both data acquisition and data interpretation required to help reduce the risk of underperforming assets and the uncertainty of field development.

Now, three-dimensional (3D) full-azimuth wide-azimuth seismic data are the norm for new data acquisitions in the US market, and the re-processing of old data sets is being completed across most of the US. Abroad, data acquisition systems are less available and thus cost more to use, so the expected return on investment for such an endeavor is less favorable. This technology enables the use of reservoir attributes, such as fluid type, geomechanics, and even permeability and porosity estimations, as well as other nascent properties, such as anisotropy (or the heterogeneous nature of rock systems). These are in addition to the normal usage of seismic for structure analysis, fault and subsurface barrier identification, and estimations of oil and gas in place.

Section 3: Infrastructure

There are many components to infrastructure that are necessary for the development of any oil and gas project, but several are crucial to the success of unconventional resources and are not present in conventional projects. Major infrastructure issues include pipelines, facility separation, gas handling, liquids handling, surface roads, rail lines, storage, water availability, housing, living condition support, water, proppant, maintenance, and personnel.

The development of early unconventional reservoirs was enabled by an established infrastructure. The clearest example is the Barnett shale in North Texas, where an existing highway and county road infrastructure in proximity to the Dallas/Fort Worth metroplex, legacy oil and gas handling capacity, rail line infrastructure, etc., created a low-cost working environment for entrepreneurial oil and gas companies to pioneer shale development.

Following this early economic success, the shale development model expanded across the US. However, limiting factors, such as the slow ramp of the Bakken shale in North Dakota and the constrained growth of the Marcellus and Utica shales in West Virginia, Pennsylvania, and Ohio, hindered progress. In the US, it is well within the capabilities of the economy, state and federal government, and industries to overcome infrastructure challenges to facilitate and enable economic development. This is not so true in other global locations, such as China, Russia, Australia, Argentina, India, or Europe. Within each of the geographical regions, the required infrastructure has not necessarily been previously established, thus placing the burden of development on the oil and gas industry, in part or fully, increasing the associated costs and barriers to economic viability.

Section 4: Political/Social

The fourth contributing component to the development of unconventional resources is having a political and social capability to produce oil and gas, including a market clearinghouse permitting profits to be obtained by all parties involved, including land owners, mineral rights owners, service companies, oil and gas operators, and government entities. In this regard, significant variability exists across both international and domestic geographies.

The US has a significant enabling social driver to shale development; namely, mineral rights ownership across private lands. This is a federally protected right that is not available in many other nation states. As such, mineral rights owners (who may or may not be the land owners) have the right to monetize their mineral interests for economic benefit. In most of the world, this is not the case, and the mineral interest owner is the government entity. Therefore, private citizens of those nations have more limited access to the wealth creation of mineral rights ownership.

Conclusion

The sustainable success of unconventional resource development is a four-fold mechanism comprising geology/geography, technology, infrastructure, and political/social elements. Each of these is integral, and without all four components, sustainable development can be strained or even prevented.

References

Rickman, R., Mullen, M., Petre, E. et al. 2008. A practical use of shale petrophysics for stimulation design optimization; all shale plays are not clones of the Barnett shale. Paper SPE 115258 presented at the SPE Annual Technical Conference and Exhibition, Denver, Colorado, USA, 21–24 September.

Sondergeld, C.H., Newsham, K.E., Comisky, J.T. et al. 2010. Petrophysical considerations in evaluating and producing shale gas resources. Paper SPE 131768 presented at the SPE Unconventional Gas Conference, Pittsburgh, Pennsylvania, USA, 23–25 February.

King, G.E . 2010. Thirty Years of Gas Shale Fracturing: What Have We Learned? Paper SPE 133456 presented at the SPE Annual Technical Conference and Exhibition, Florence, Italy, 19–22 September.