New Albany Shale Gas Research Project

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Introduction/Background

Gas Technology Institute (GTI) is engaged in a research and development project aimed at the development of techniques and methods for increasing the success ratio and productivity of New Albany shale gas wells to a level where the otherwise noncommercial wells may become commercial producers. The efforts are funded by Research Partnership to Secure Energy for America (RPSEA) and supported by several producing companies targeting the development of the New Albany gas shale. Although the project is aimed at the development of New Albany shale gas, results will be applicable to other gas shale formations such as the Marcellus, Woodford, and Mancos as well as other low permeability gas bearing formations.

The New Albany Shale formation occurs in Illinois, Indiana, and Kentucky, but to date gas production has been primarily from western Indiana and southwest Kentucky. Figure 1 shows the boundary of the New Albany shale within the Illinois Basin and includes the hydrogen index contours for the most promising areas in the basin[1]. The volumes of in-place and technically recoverable gas in New Albany shale have been estimated to be between 86 and 160 trillion cubic feet (tcf) and 1.9 to 19.2 (tcf) respectively[1].

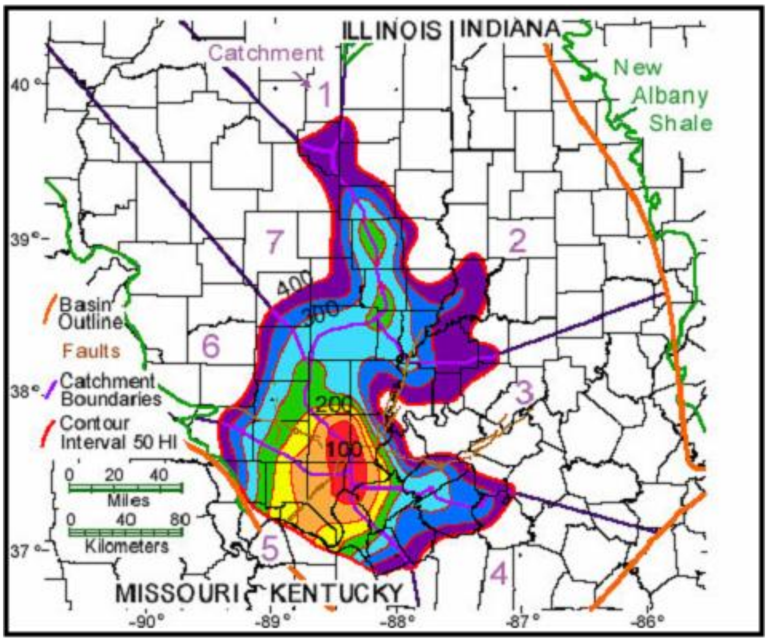

Figure 1 - Hydrogen index map for New Albany shale in the Illinois Basin – USGS Open File Reference 2.

The New Albany shale project is a field-based industry cooperative project with producer involvement and support, which combines scientific and technical analyses with field data acquisition, testing, and field validation.

Eight producing companies (Atlas America, Aurora Oil and Gas Corporation, Breitburn Energy, CNXGas, Diversified Operating Corp., NGAS, Noble Energy, and Trendwell Energy Corp.) and nine research organizations (GTI, Texas A&M University, Bureau of Economic Geology (University of Texas), West Virginia University, Amherst College, University of Massachusetts, Pinnacle Technologies, and ResTech) are participating in this project.

GTI has assembled a team of highly qualified experts with outstanding background and experience to implement the project. A comprehensive integrated project plan for geological, geochemical, reservoir engineering, and production stimulation studies and a detailed field data acquisition and testing plan addressing all major issues have been prepared. Figure 2 is a graphical representation of the project structure depicting the flow of information and data between various project elements.

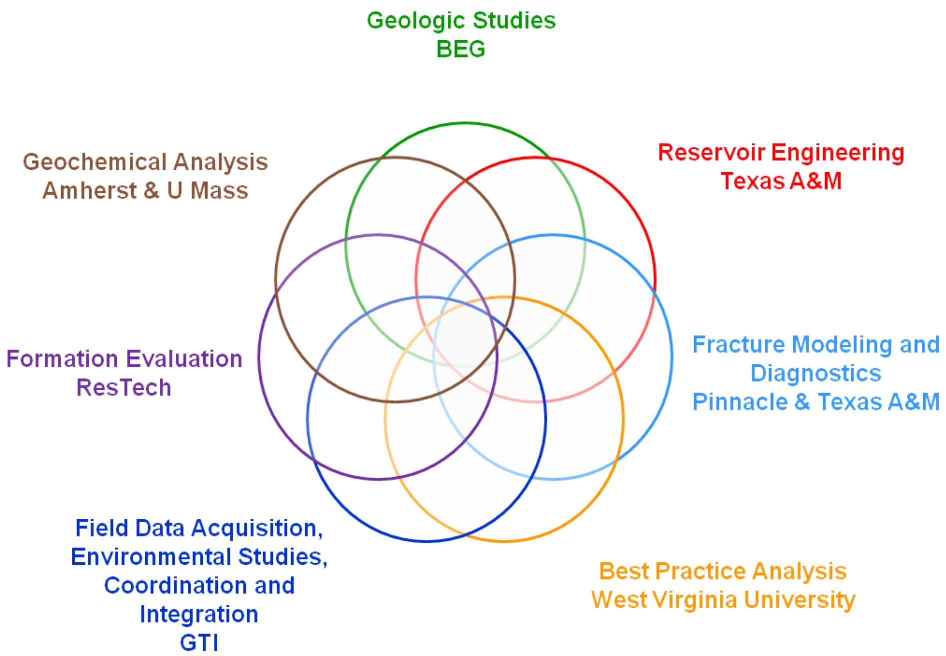

Figure 2 - New Albany Gas Shale Project Structure

Objectives

As with other shale gas resources, production from the New Albany shale is primarily from natural fractures. However, because of extremely low matrix permeability and limited open natural fractures, commercial production from the New Albany shale is normally achieved by interconnecting the natural fractures through hydraulic fracture stimulations. As such, the primary objectives of this project are to develop techniques and methods for identification and characterization of natural fractures and to develop effective fracture stimulation techniques, leading to commercially acceptable production rate and ultimate recovery. It needs to be mentioned that the New Albany shale is underlain by water bearing Devonian formation in some areas and this geology adds an additional problem for effective hydraulic fracturing, as the fractures should not be allowed to grow into the water bearing zone.

Development/Methods

The methodology being applied to the New Albany Shale research effort includes integration of all the necessary aspects of developing a shale resource. Projects will be conducted in each of the following technical areas.

a. Geological Studies

Because of the low matrix permeability characteristic of the New Albany shale, natural fractures are the main contributors to flow, and production at a commercial rate can only be achieved by proper placement of horizontal wells relative to dominant fracture orientation. High permeability areas (sweet spots) occur in regions with high fracture intensity. Characterization of the key fracture attributes of orientation, size distribution, intensity, and porosity/occlusion patterns is of primary importance. The work includes application of new techniques to quantify the spatial arrangement of fractures including potential clusters of large open fractures. Key parameters will be assessed through examination of a combination of data types. The most important will be cores, vertical and horizontal well image logs, and drilling and production data. Fracture orientation, intensity, and spatial distribution information will be obtained from core and image log data.

Samples have been selected from cores to be made into polished thin sections to examine the mineral fill of the fractures. Scanning electron microscope (SEM) imagery will be also used. A suite of fracture attribute characterizations for selected areas will be prepared, which may include maps for attributes such as orientation, and models for attributes such as mineral fill, size distribution and intensity. At this stage, we will identify those attributes with first order control over gas production as a tool for identification of high-potential areas of the basin.

b. Geochemical Analysis

Hydrocarbon gases contained in the New Albany shale consist of thermogenic gas evolved from thermally matured organic material and biogenic methane resulting from bacterial digestion of carbon compounds. While the evolution of thermogenic methane normally ceases upon uplift of the formation, bacterial activities continue as long as the environment remains amenable to bacterial growth. To arrive at a reliable resource estimate and to identify favorable regions within the basin, a comprehensive geochemical investigation is being performed. Key activities include field data acquisition, including sampling of gas and co-produced water, as well as laboratory tests including gas chromatography and mass spectropy for measurement of total organic content. In addition, the microbial population of the New Albany shale will be determined from water samples. Planned data analysis also includes microbial analysis consisting of DAPI-stained cell counts from individual wells, molecular fingerprinting based on total DNA for community structure, and total RNA to identify active community members. Attempts will be made to isolate and culture novel methanogens to determine rates of methane production. Also, microbial community structure in the New Albany shale will be compared with that of the Antrim Shale to assess whether any observed differences influence production rates and total gas content in the shales.

c. Formation Evaluation

Identification of producing zones in New Albany shale wells and determination of reservoir properties from well logs is a nontrivial problem. Intrinsic physical properties of shale are such that conventional formation evaluation techniques are not applicable, and techniques specific to the New Albany shale must be developed. Emphasis will be placed on borehole imaging, coring, and geochemical techniques as well as seismic imaging where possible. The activities identified for this task include fracture identification from logs such as FMI, CAST and construction of borehole maps of dip projections of fractures within specific distances from boreholes. Log analysis work includes the development of advanced methodology for calculation of shale porosity, water and bitumen saturations, free gas saturation, and adsorbed gas through correlation with core data.

d. Reservoir Engineering

Pressure buildup tests in horizontal and hydraulically fractured wells can be difficult to interpret because these tests involve many unknown parameters and pressure transient tests require very long durations (*i.e.,* months). Producers need to have a reliable estimate of production to make decisions regarding well completion and to evaluate the financial and operational requirements of the field. This effort is devoted to the analysis/interpretation of the available pressure transient test data obtained from the gas shales study area as well as new pressure transient data. Production data analysis is focused on production analysis for horizontal and hydraulically fractured wells. In addition, the project plans to develop new pressure transient models for horizontal and fractured wells.

e. Fracture Modeling

Commercial production from tight sands and shale formations invariably involves hydraulic fracturing of the formation. Although several hydraulic fracturing simulators have been developed during the last twenty years, none is capable of predicting fracture growth in the presence of natural fractures. In particular, it is necessary to use a model capable of dealing with injection-induced fracture propagation near natural discontinuities such as joints, faults, and bedding planes. The work in this area is focused on the development of knowledge and analytic models for such fractures.

f. Fracture Design and Fracture Diagnostics

Design and quality control of fracture stimulations and fracture diagnostic surveys using tiltmeter and microseismic fracture imaging for independent verification of fracture design as well as monitoring and control of fracture growth is absolutely critical. Integration of stimulation, production data, and reservoir engineering technologies will be performed to successfully evaluate and optimize hydraulic fracturing of the reservoirs. Current completion/stimulation practices will be evaluated in the New Albany Shale and field experiments will be conducted to measure hydraulic fracture geometry and evaluate stimulation effectiveness. Integration of the results of field experiments with geologic, geophysical, completion and production data to optimize development of the New Albany shale will be conducted.

g. Best Practice Analysis

The intent of best practice analysis is to compile drilling, completion, fracture stimulation, and production and create a comprehensive database that reflects the range of practices in the New Albany shale. Once the database is populated with data from a statistically significant number of wells, a series of objective numerical analyses based on fuzzy logic and artificial intelligence techniques will be carried out to determine the optimal combination of operational parameters that result in the most favorable production instances. Upon completion of these analyses results will be verified with hard data from the field and augment the data driven results with engineering driven conclusions to arrive at field-verified best practices for drilling and completion of New Albany shale wells.

h. Environmental and Water Management Studies

The shift of New Albany shale gas from an emerging to an existing resource category entails drilling and completion of thousands of wells, establishment of gathering systems, processing plants, compressor stations, and so forth. Subsequent to determination of substantial producible reserve and upon identification of technically effective and economically optimal development technologies, determination of environmental impacts of these operations and facilities in terms of water requirement and waste management is an imperative. In addition, water resources to meet the needs of the upstream and downstream operations must be identified and a prudent water management scheme be designed.

i. Field Data Acquisition and Verification, Coordination and Technology Transfer

The prerequisite of success for a field-based project is the acquisition of reliable data and timely testing of results so that dependable data are provided for analytic work and designs. Procedures are checked in the field and modified based on test results. The New Albany Shale project includes extensive field data acquisition and testing including sampling, coring, logging, hydraulic fracturing, fracture diagnostics, and production logging. Specifically, two production logging, two hydraulic fracturing experiments, and four fracture diagnostic surveys are planned. In a multifaceted field-based research, prudent coordination, and open communication are of essence. Preparation of clear and comprehensive reports will be used to extend the technology beyond the limited individuals and companies, expanding the information to other applicable regions. In the New Albany shale project, all independent research organizations will prepare a stand-alone detailed report describing the scientific bases and results from their work. The work of the various contributors will be used to develop an integrated analysis of the factors controlling economic production in the New Albany Shale, which will be captured in Best Practices recommendations.

Results

Experimental results established thus far as part of the ongoing research experiment are reported in the following sections.

Geologic Study Results[3]

The primary geologic focus is on description and characterization of natural fractures in the New Albany Shale. Outcrops of New Albany Shale in Kentucky and Indiana were visited and sampled. In addition, several cores were viewed and sampled for further investigations. Because production from the New Albany Shale is primarily from natural fractures, knowledge of the orientation of dominant fracture system is critical for placement of horizontal wells such that these wells intersect the maximum number of fractures

One of the best exposures of the regional joint pattern occurs on the Indiana bank of the Ohio River at New Albany (Fig. 3). The dominant joint set trends ENE, individual fractures extending several hundreds of feet. A secondary set trend almost orthogonal to the dominant set, but abutting relationships suggest they are broadly coeval. Both joint sets are steeply dipping and have no mineralization on the joint.

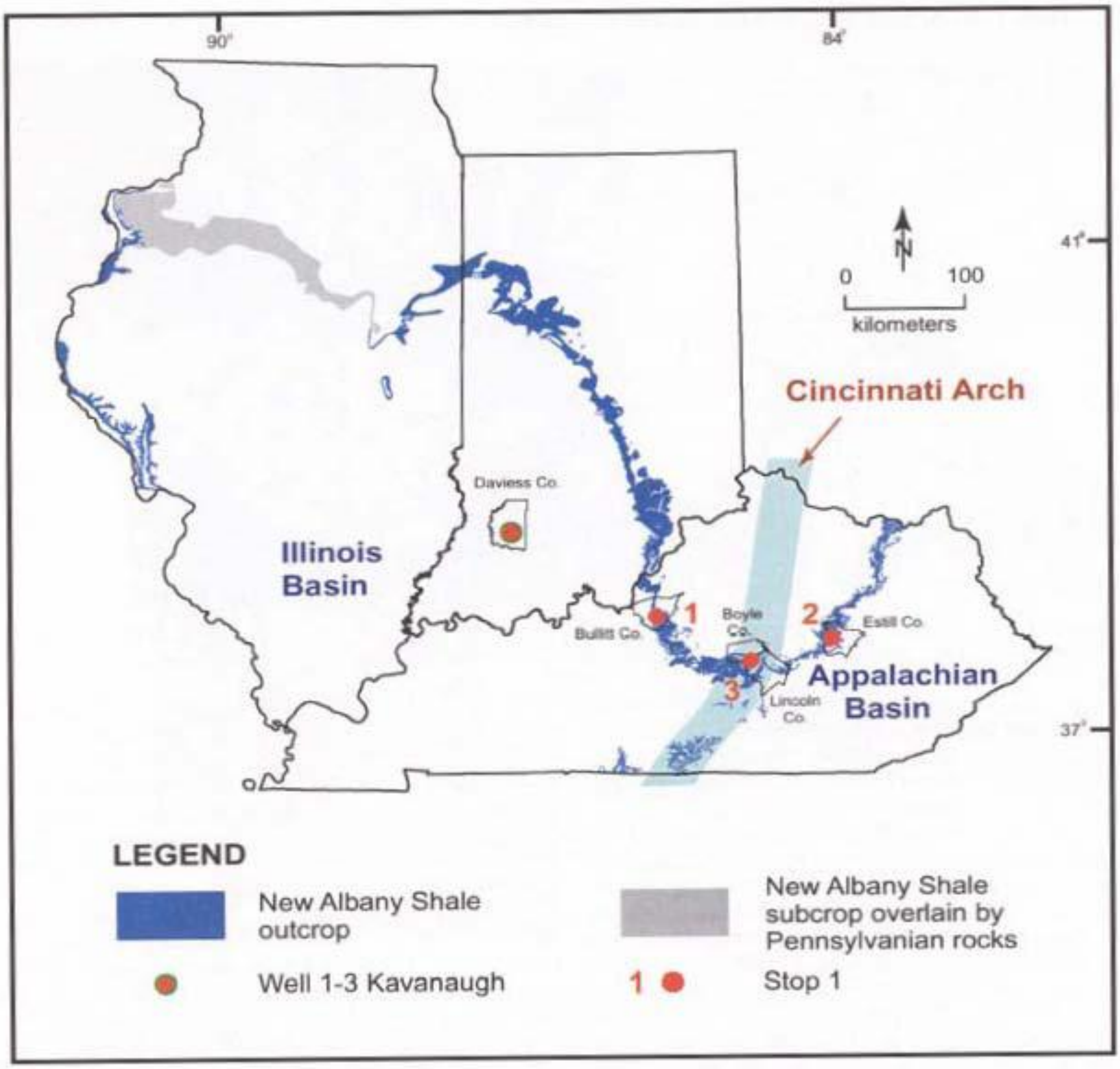

Figure 3 - Map Illustrating New Albany Shale Outcrop Area[3]

Barren joints were not observed in the cores that were examined. The barren fractures in core that were observed are interpreted as being induced fractures on the basis of petal centerline geometries, and the observation that they did not have the oxide staining that is ubiquitous in outcrop. It is important to establish the significance of these fractures relative to both biogenic and thermogenic parts of the play.

Many other fractures in core and outcrop were observed and are of interest and merit further study. These are described briefly below, along with a statement of how they may or may not be relevant for gas production.

Compacted fibrous quartz-dolomite-bitumen veins were observed in outcrops. The veins are very wide relative to their height, and commonly contain bitumen in vuggy openings, termed geodes by other workers. These large veins were not observed in the cores. However, in the outcrops and cores we did observe smaller fractures, confined to pyrite-rich layers that also show compaction structures, and that provide support structures for the bedding and compaction fabric, which is deflected down on either side of the fracture (Fig. 4). It is not known at this stage if these small fractures are related in any way to the large fractures.

Figure 4 - Small, Early, Compacted Veins, Fill Likely Dolomite; and (picture to right) Example from New Albany Shale Core at 2,804 ft. Height of Fractures Approximately 3 cm. Reference 3.

It is unlikely that these large veins will affect production as they seem to be mostly confined to the Blocher Member, which is well below the usually targeted Clegg Creek Member. However, our observations so far are restricted to a very few outcrops. Vertical cores may not sample them as they are spaced several meters apart. They are worth further study, however, because they record fluid conditions at an early point in the burial of the New Albany Shale. The smaller veins are apparently more widespread, but because they are confined to pyrite layers may not affect production significantly. However, arrays of small veins can act as mechanical discontinuities for hydraulic fractures causing the hydraulic fractures to split or be deflected.

In the underlying limestone and the very base of the Blocher Member there is a second set of filled fractures. These are networks or en echelon arrays and are calcite filled. These are not compacted and areinterpreted to be later than the dolomite-quartz filled veins described above.

In the cores several examples of steep, sealed, or partly sealed fractures were observed. Some have smeared cement fill and have been interpreted as faults. These sets are likely to be important either for enhancing permeability or as influences over hydraulic fracture propagation.

Because of the difference in depth of the biogenic and thermogenic plays we think that the barren joints are of possible importance for the biogenic play but are unlikely to play a role in the thermogenic play. The fractures observed in core could all potentially play a role in either directly influencing the permeability or affecting hydraulic fracture propagation.

Well Drilling and Completion[4]

Multiple well drilling and completion geometries have been investigated within the New Albany Shale including the following list of geometries:

- Open hole lateral wells with cased sump
    - Vertical pilot holes
    - Deviated pilot holes
- Open hole lateral wells with no sump
- Intersection of vertical well with open hole lateral
    - Intersection occurs in early portion of lateral
    - Intersection occurs at toe of lateral
- Multiple open hole laterals
- Stacked
- Dual opposing
- V-shaped
- Pitchfork

Horizontal and high angle lateral wells are developing as the preferred geometry as opposed to vertical holes although vertical wells are still being considered. Figure 5 illustrates a open hole lateral well geometry.

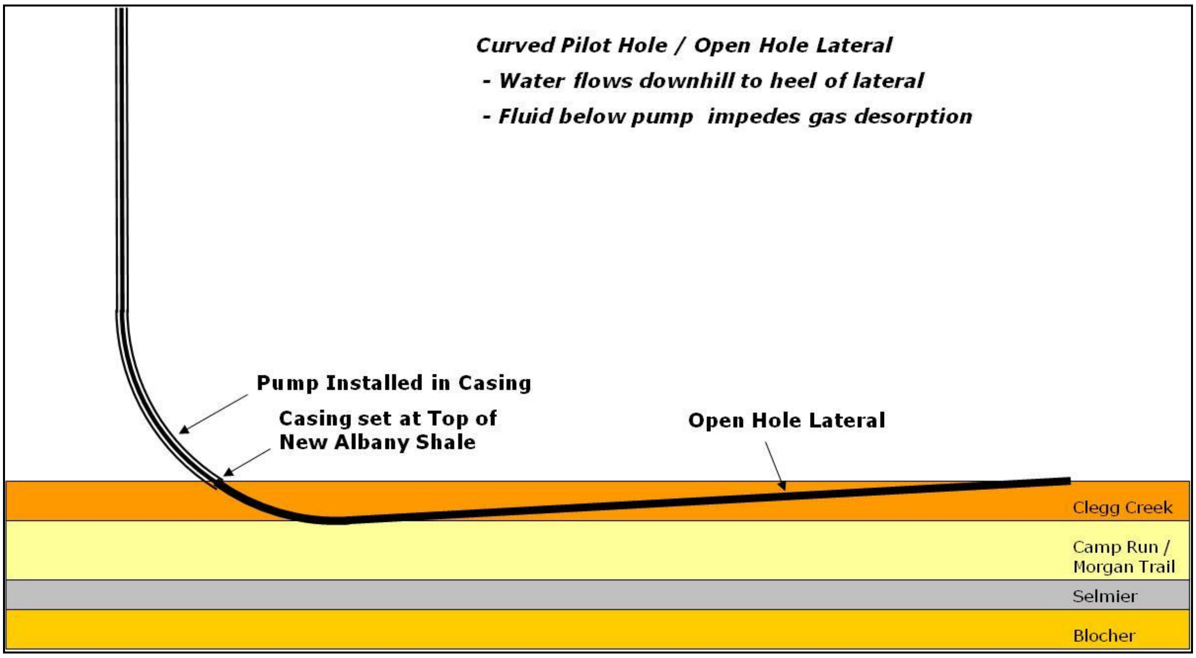

Figure 5 – Toe-up Open Hole Lateral Well Completion Geometry (From John Hunter, Aurora Oil and Gas[4]

The concept is to drill a long lateral section of the New Albany shale with the end (toe) of the wellbore higher than the wellbore portion (heel) near the vertical section. This allows any water produced in the open hole section to flow downhill to the heel section where it can be pumped out of the well by a downhole pump placed in the cased section of the wellbore.

Well geometries of this type can be fractured or produced without fracture stimulation treatments. While stimulation is the preferred approach some areas of the New Albany are underlain by a water wet dolomite formation. If fracture treatments grow downward to this section the well economics can be negatively impacted by the subsequent water production.

In areas where the water wet dolomite is not an issue the preferred completion procedure usually includes hydraulic stimulation. A number of issues need to be considered for proper well completion design including the following items:

- Cost containment
    - Necessary for acceptable economics

- Open hole lateral(s) with no stimulation required
    - Prior local knowledge of reservoir needed
    - Minimize reservoir damage while drilling

- Assume that stimulation will be required?
    - High volume acid treatment to dissolve calcite
    - Fracture stimulation to connect with natural fractures
    - Open hole vs. cased hole

- Recover gas reserves from all organic members?
    - Most laterals have targeted only the Clegg Creek member
    - Blocher member is generally separated by impermeable Selmier member

- Optimize drilling geometry for pump placement
    - Necessary for water removal and reduction of back pressure

Hydraulic Fracturing and Hydraulic Fracture Design[5]

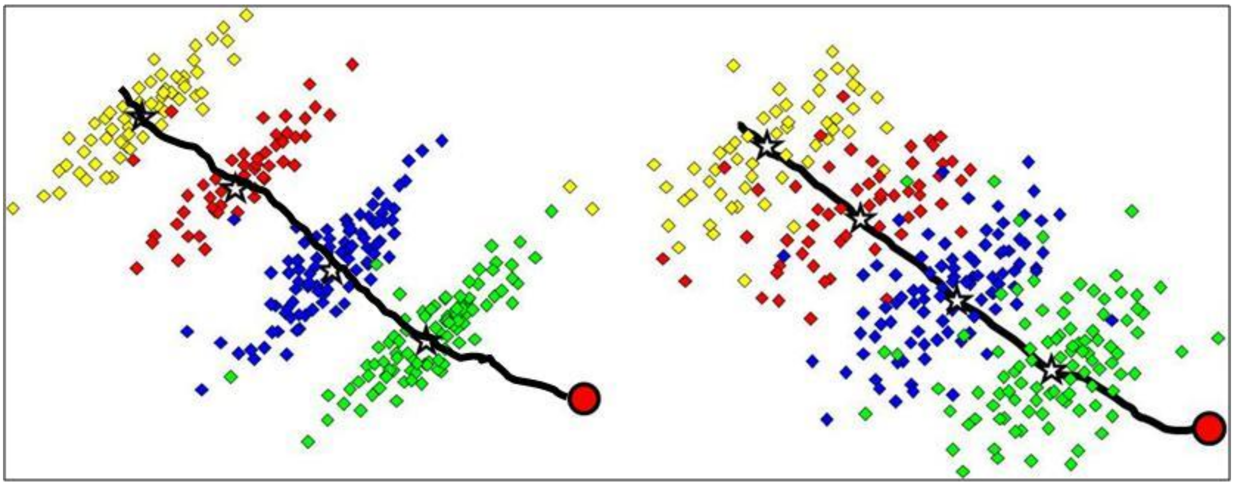

Figure – 6 Possible Hydraulic Fracture Configurations in the New Albany Shale[5]

The research efforts on hydraulic fracturing are focusing on the potential to model a New Albany Shale hydraulic fracture treatment with a 3-D fracture simulator. Results to date indicate this is a difficult task to accomplish. Figure 6 is a plan view of two horizontal wells each being fracture stimulated at four points. On this figure, the colored dots denote the location microseismic events associated with hydraulic fracturing. Note that a simple bi-wing induced fracture (left side Figure 6) may be an indication of a lack of natural fracturing. This can be a real problem in a marginal play in that a substantially reduced surface area is exposed to the reservoir creating challenging well economics.

If the natural fracture network consists of multiple parallel and orthogonal induced fractures then the likely hydraulic fracture development is most likely to resemble the geometry depicted on the right hand side of Figure 6. It should be noted that this case is beyond the capability of most hydraulic fracture simulators to adequately model. This creates a potential conundrum that only uneconomic wells can be adequately modeled by current simulators.

Experience thus far in the New Albany Shale with hydraulic fracturing has yielded a cross section of experiences with varying results. Large waterfracs in a shallow, normally pressured shale may not be viable due to the inability to adequately recover the fracturing fluids. Substantial experimentation with 70 to 85 quality foams has indicated that large foam fracture treatments may be acceptable in terms of preventing water blockage, but generally have unacceptable viscosity. Foam viscosity can be 80 to 100 times that of water and 4,000 to 5,000 times that of nitrogen. Low viscosity promotes network complexity while high viscosity promotes fracture simplicity.

Straight nitrogen is utilized in the shallower New Albany Shale wells almost exclusively. Some limited experimentation is taking place with high quality (+95 quality) foam systems as well as misting fluids using propane and other mechanisms to reduce water and lower viscosity. A major paradigm shift may be necessary for hydraulic fracture stimulations in order to make the New Albany Shale a first class shale resource

Production Methods[4]

The New Albany Shale in many regions produces some water which needs to be removed from the wellbore to allow gas to flow unimpeded. Also, in the areas where hydraulic fracture treatments are conducted there is a considerable volume of treatment water that needs to be removed from the wellbore. The Initial pump of choice for some operators is the progressive cavity pump (Figure 7 – for surface configuration of progressive cavity pump) which is well suited for high water volumes. It is however problematic when installed in curved wellbores.

Figure 7–Surface Configuration for Progressive Cavity Pump – From Aurora Oil and Gas[4]

Electrical Submersible Pumps (ESP) are utilized in some areas where well depths exceed the depth at which water well pumps can be utilized. These pumps are more expensive but required due to the depth from which pumping must take place. Heat generated by electrical submersible pumps (ESP) may result in rapid calcium carbonate scale buildup which is another production characteristic that must be considered.

Gas lift is another water handling procedure being tested by some operators. At least two operators have employed chamber-lift method in horizontal wells with mixed success

Beam pumps (Figure 8) are evolving into a preferred production method for handling water production in the New Albany shale. Operators need to be prepared for corrosion and scale issues that impact tubing and rods.

Figure 8 - Beam Pump Installed on Flood Plain in New Albany Shale Region, Illinois Basin[4]

Gas Production Infrastructure[4]
Gas production infrastructure needs for producing New Albany Shale gas is strongly related to the low volume low pressure production characteristics encountered. Specifically, the objective is to minimize back pressure in order to enable low reservoir pressures to maximize gas desorption. This requires both low pressure gathering systems and low pressure production facilities be designed and installed. Very often large diameter polyethylene pipe is used for both gas production lines and lines for moving water to disposal facilities (Figure 9).

Figure 9 - New Albany Shale Gas and Water Lines Prior to Burial[4]

Compressor stations are located both at satellite locations and central facilities. Satellite locations are the first stage of compression and are usually electric modular screw compressors providing the first stage of compression. These electric compressors provide for lower capital cost, lower maintenance and are environmentally preferred. Reciprocating compressors provide 3 stages of compression to attain pipeline pressure and are normally located at a central production facility and can be either electric or gas driven.

The advantages of this low pressure system design provide a significant reduction in capital expenditures. Increased production rates are realized due to reduced back pressure on the wells and the commercial life of wells is extended due to reduced costs. Facility capacities can be optimized over the life of the wells as development takes place based on economics and technical factors.

New Albany Shale Production and Reserves[4]

The peak gas production volumes for most New Albany Shale wells are usually attained in the first 30 days of well production. This is followed by a somewhat immediate and significant production decline followed by a shallow hyperbolic decline. Gas reserves are long-lived with production occurring up to 50 years. Figure 10 illustrates expected production from a New Albany Shale horizontal well with a 2500 ft. lateral section. Initial gas production rates are on the order of 275 mcf/day declining to 100 mcf/day in the first 24 months of production. Initial water rates are on the order of 200 bbls per day declining to 70 bbls per day after 24 months. Cumulative gas production estimated after 40 years is just over 1 billion cubic feet of gas.

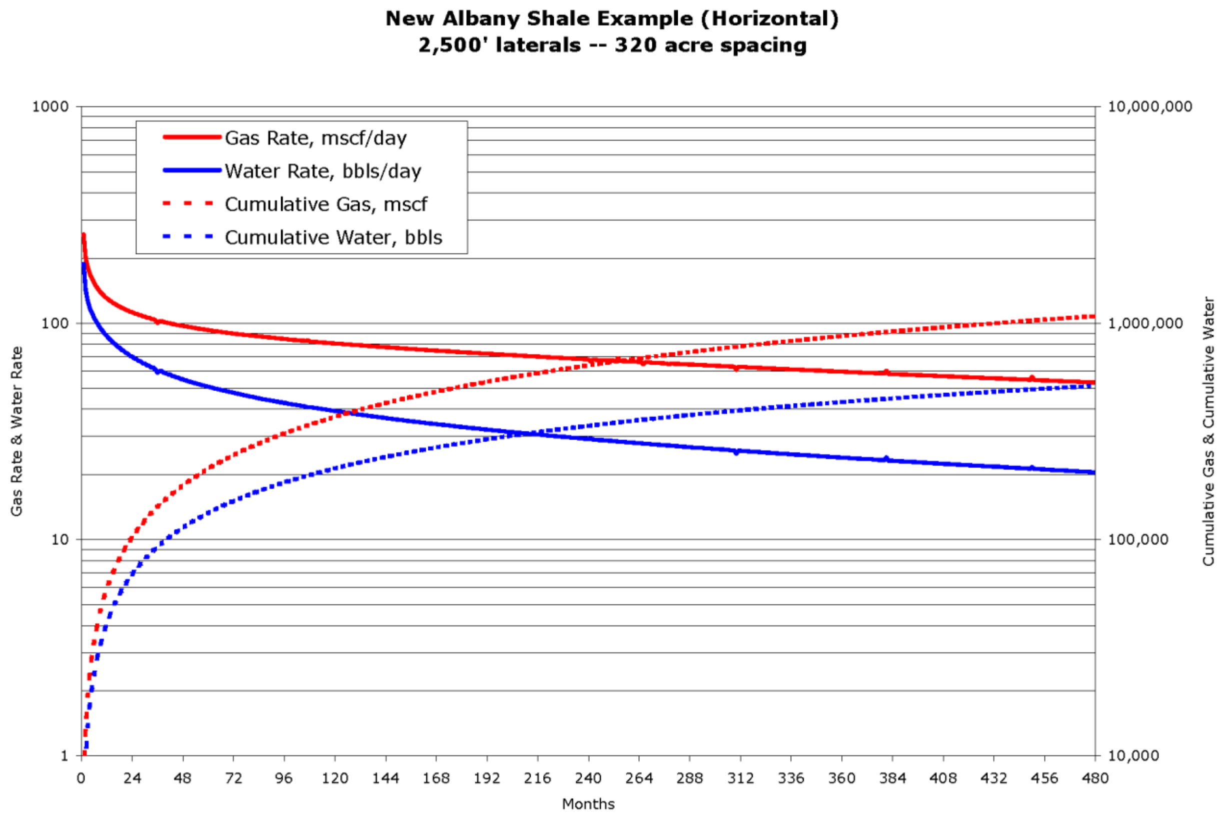

Figure 10 – New Albany Shale Gas Production Profile for a 2500 ft. Horizontal Well[4]

Well costs for a New Albany Shale horizontal well with hydraulic fracture stimulation can exceed one million U.S. dollars. In addition to this capital investment are operating expenses over a long time period (40 Years). Operating expenses can include water lifting, transport and disposal, gas compression, well workovers to maintain pumps, gas processing expenses to remove CO2 and nitrogen and road and site maintenance. Other expenses include royalties and severance taxes.

Overall economics surrounding the current New Albany Shale are very challenging at today's gas prices.

Summary/Conclusions/Perspectives

The New Albany Shale contains vast reserves of natural gas, but technological challenges have posed a hindrance to economic development. A number of active horizontal drilling programs are currently underway to extract biogenic gas.

The naturally fractured rock supporting biogenic gas generation in the New Albany Shale is not particularly similar to other well-publicized shale plays. Care should be taken when transferring outside technologies to the New Albany Shale. A number of elements need to be collectively considered for development of the New Albany Shale resource as well as other shales. Figure 11 illustrates eight important areas that should be investigated for every play[6]. The importance of each of these elements can be different for each shale play and can contribute to the success of the play in different ways and varying quantitative values. Each should be carefully examined.

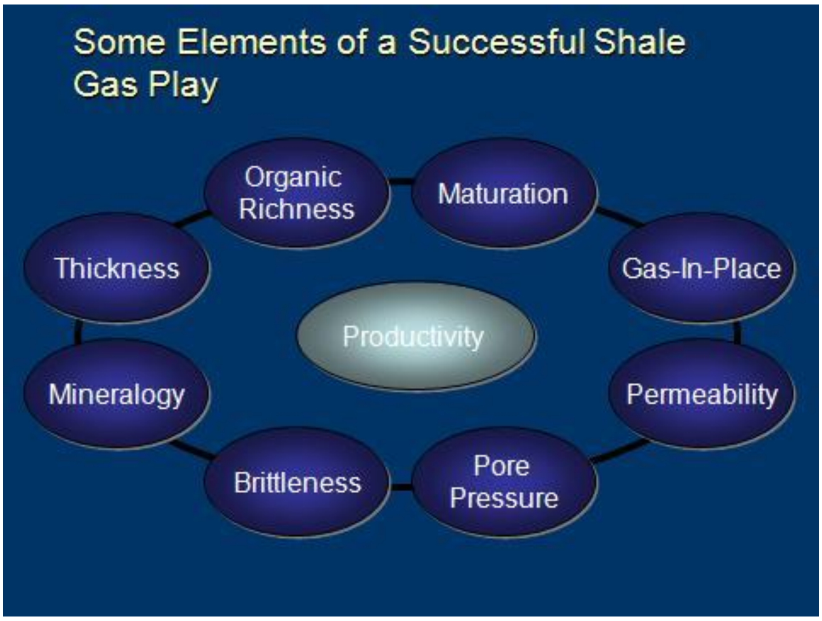

Figure 11 – Elements to be Considered for Development of a Successful Gas Shale Play[6]

Well drilling and completion design is then based on the attributes of the play as determined by the geosciences topics investigated early in the cycle life. Each shale play can differ significantly and with the New Albany Shale there can be significant differences from one portion of the Illinois Geologic Basin to another part of the basin. Carefully consideration of all elements for success and using caution when transferring a technology that has worked in another region without careful field testing will be of ongoing importance.

New research continues to investigate the most effective well completion design and practices and will need to continue to unlock this vast gas resource.

Acknowledgements

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