Schlumberger

Well Evaluation

An Integrated Well-Evaluation
Process for **Shale Gas Reservoirs**

APPLICATION

Gas shale analysis for unconventional wells

BENEFITS

- Optimized stimulation by thorough study and planning
- Increased recovery efficiencies through fracture stimulation
- Resource gas turned into reserve gas with economical extraction
- Well producibility predicted for long-term planning
- Fracture geometry information for more precise drilling
- Simulator modeling to predict production for naturally fractured shales

FEATURES

- Recommended coring program
- Seismic tie
- Computed rock stresses
- Delineated shale gas bed
- Quantified amount of gas
- Calculated permeability, a critical parameter
- Mapped fractures and estimated apertures
- Tested wellbores

AN INTEGRATED WELL-EVALUATION PROCESS

Schlumberger is the recognized leader in gas shale evaluation. Shale gas has opened a new chapter in resource recovery, going after the gas in the source rock, the last place left to develop.

Delineating a general area of potential shale gas deposits is just the beginning of a complex process of evaluating the commercial prospects of a field. Schlumberger has created a unique, integrated approach to evaluating gas shales, producing detailed, accurate answers to the key questions facing the customer:

- What is the gas in place?
- What is the producibility?
- What is the near- and long-term production potential?

To answer these questions, Schlumberger draws on its unparalleled experience in gas shale development and an extensive suite of proven tools and innovative technologies, including those featured here.

ECS TOOL

The innovative ECS* Elemental Capture Spectroscopy logging tool provides in-situ geochemical analysis. It uses proprietary technologies to calculate clay and quartz volumes, and sulfur and pyrite content to yield a prediction of shale gas content.

The ECS tool provides a continuous measure of the concentrations of Si, Ca, Fe, S, Ti, Gd, K, Mg and calculated Al. These concentrations can be readily converted to porosity-independent lithology, including weight percent clay, carbonate, quartz-feldspar-mica and pyrite.

Applications for shale gas evaluation include:

- Accurate clay content estimation independent of conventional log measurements
- Element-corrected matrix density
- Kerogen (adsorbed gas) content and effective porosity/Sw (free gas) when combined with Platform Express* and gamma ray logs
- Estimation of adsorbed gas in SCF/ton

ELANPlus AND SHALEGAS EVALUATION

Evaluation of ECS data and Platform Express* logs (porosity logs in cased hole) is the basis of resource evaluation. Processing string includes:

- SpectroLith* ECS evaluation that converts elemental concentrations from ECS* tool or RST* Reservoir Saturation Tool to major minerals groups (clay, carbonate, etc.)
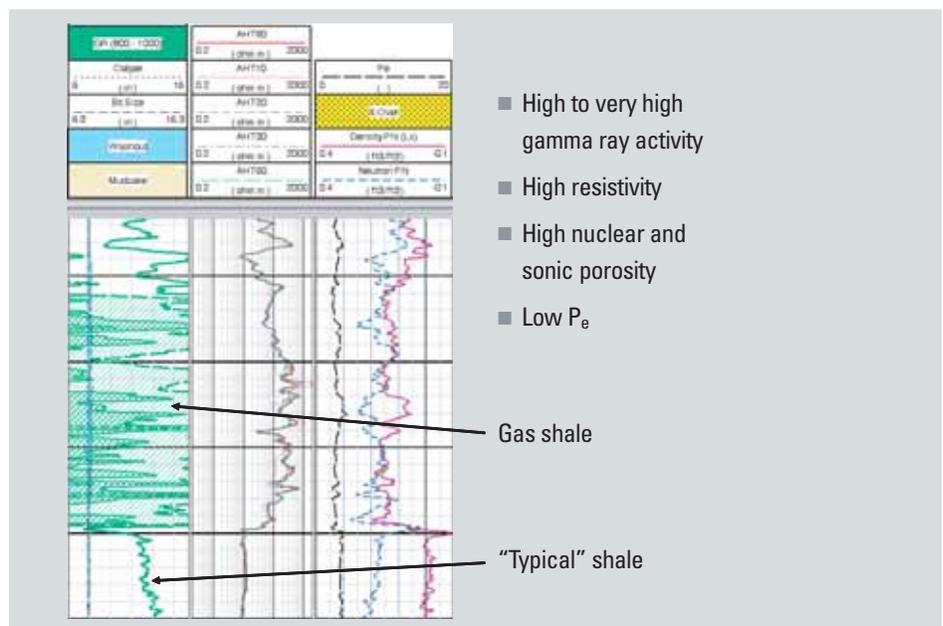

- High to very high gamma ray activity
- High resistivity
- High nuclear and sonic porosity
- Low P_e

Gas shale

"Typical" shale

Figure 1: Gas shale log

- ELANPlus* combination of SpectroLith and Platform Express data to calculate lithology, total and effective porosity, saturations, and kerogen content

- ShaleGAS incorporation of core calibration to calculate TOC; adsorbed, free and total gas throughout the entire gas shale in units of SCF/ton; and cumulative estimates of adsorbed, free and total gas in place in BCF/section.

QUANTIFYING TOTAL GAS IN PLACE

Determining the total amount of gas in shale is an essential step in determining the viability of a given play. This process has been made much more accurate by recent breakthroughs in analytical tools and methodologies. In outline, the process involves:

- Solving for the volume of kerogen, the organic component of the shale

- Converting kerogen volume to Total Organic Carbon (TOC)

- Using the Langmuir isotherm to calculate Total Gas in Place (GIP)

- Confirming and calibrating calculations through core analysis

SOLVING FOR KEROGEN

Kerogen is the organic material in the rock. It both generates the gas and chemically holds it in place by adsorption. The distinguishing petrophysical properties of kerogen include a relatively low density (1.2 g/cm^3) and a very high gamma ray activity (500-4,000 or higher). Historically, estimations of organic content were based primarily on gamma ray, density and resistivity logs, but various factors limited the effectiveness of this approach.

For example, it was impossible to determine to what extent a low density reading was due to the presence of kerogen and to what extent to porosity (Figure 1).

Schlumberger utilizes the ECS innovative geochemical log tool to achieve a much more accurate determination of kerogen (Figure 2). The ECS tool measures a series of elements including silica, calcium, iron, sulfur, potassium
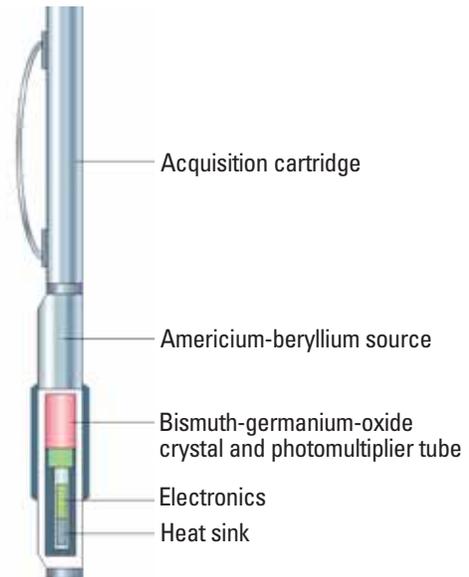

Figure 2: ECS provides a way to accurately determine kerogen

and titanium, none of which occur in the kerogen. It provides a basic lithology which allows us to separate the measurement of porosity and organic matter, and arrive at a significantly more accurate estimation of kerogen volume (Figure 3).

CONVERSION TO TOTAL ORGANIC CARBON

TOC is the total carbon contained in the kerogen. We calculate TOC using ELANPlus software, based on RHOB (density), gamma ray, Pe and SpectraLith lithology data. A key factor in the conversion is the maturity constant, which reflects the concentration of carbon in kerogen over time.

CALCULATING TOTAL GAS IN PLACE USING LANGMUIR ISOTHERM

It is essential to know how much of the TOC is in the form of gas which has adsorbed onto the kerogen, as distinct from free gas in pores or fractures. Using the Langmuir isotherm equation, we derive a gas content.

CORE ANALYSIS

Core analysis is a valuable tool to verify and correct the estimations of gas content and producibility, and has been used in a third of the shale gas wells analyzed by Schlumberger. Recommended core measurements include:

- Capillary suction test
- Fluid sensitivity
- Permeability and pressure
- Sw, soil, KINT
- TOC
- Maturation
- X-ray diffraction
- Bulk and clay mineralogy
- Langmuir isotherm
- Adsorbed gas
- Vitrinite reflectance

PressureXpress

The PressureXpress* service provides fast, accurate pressure and mobility measurements while logging, reducing the pressure testing process to less than a minute in most cases. Data is acquired in a fraction of the acquisition time required by multifunction formation testers.

Unlike conventional formation pressure test tools, the PressureXpress service gives you pressure and fluid mobility measurements during the first logging run. It quickly generates a survey of reservoir pressure for connectivity analysis, a pressure gradient for fluid density and fluid contact information, and fluid mobility data to aid in sampling-point selection.

These data are the basis for accurate pressure profiles and mobility measurements that can be integrated with petrophysical, seismic and conventional log data for a more complete reservoir picture.

The tool's OD and profile greatly reduce the risk of sticking. The eccentered tool shape, combined with a slight overbalance in setting force by the backup anchoring pistons, ensures an integral $\frac{1}{2}$-in. standoff from the formation during pretesting. The smooth tool profile minimizes mudcake scraping when the PressureXpress tool is run in the hole.

Sonic Scanner

The Sonic Scanner* tool is used to measure anisotropy and mechanical properties, providing essential axial, azimuthal and radial information. Derived from both monopole and dipole measurements for near-wellbore and far-field slowness, this information is vital for a better understanding of the reservoir.

The Sonic Scanner tool enables accurate radial and axial measurements of the stress-dependent properties of the rocks near the wellbore. Its multiple depths of investigation, excellent waveform quality and clear presentations reduce the complexity of sonic logging without compromising the depth of information.

The Sonic Scanner tool provides advanced types of acoustic measurements, including borehole-compensated monopole with long and short spacings, cross-dipole and cement bond quality. These measurements facilitate decisions that reduce overall drilling costs, improve recovery and maximize productivity.

The Sonic Scanner tool enables accurate radial and axial measurements of the stress-dependent properties of the rocks near the wellbore. Its multiple depths of investigation, excellent waveform quality and clear presentations reduce the complexity of sonic logging without compromising the depth of information.

Benefits include enhanced hydrocarbon recovery, real-time decision making and reduced uncertainty and operating risk.

StimMAP

The StimMAP* diagnostics service maps hydraulic fracture systems as they are being created. Microseismic events triggered by the stimulation treatment are detected and located in three-dimensional space, relative to the well being treated.

StimMAP measurements can be used to ensure optimal hydraulic fracture placement and improve reservoir development.

Ultimately, this service makes it possible to incorporate stimulation procedures with reservoir characterization to optimize reservoir performance.

Before StimMAP diagnostics, fracture geometry interpretations relied on wellbore pressure response, near-wellbore diagnostics, production response or some combination of the above. StimMAP mapping utilizes microseismic data acquired with the multishuttle VSI* Versatile Seismic Imager, which has superior vector fidelity and low signal/ noise ratio, providing a high degree of certainty in event location. This VSI data can be processed on location to generate a 3D computer image of the fracture system, providing an opportunity to re-engineer the stimulation treatment of subsequent stages.

Engineers at the monitoring or treatment well communicate using the Web-based InterACT* real-time monitoring and data delivery service. Remote office locations also can be included in the communications loop, which makes data instantly accessible for processing and interpretation.

Comparing the actual fracture mapped by the StimMAP service with the FracCADE* fracturing design and evaluation software model provides useful information for improving future treatments. The lessons learned enable operators to optimize well stimulation costs and provide insight for new and in-field drilling opportunities.

Platform Express

The Platform Express platform provides a highly integrated combination of neutron porosity, density, gross gamma ray and electrical logs. It provides a high-resolution measure of formation bulk density, which is readily converted to porosity with knowledge of matrix and fluid densities. The tool also measures the photoelectric absorption index (Pe) of the formation in open boreholes.

The most commonly deployed electrical log in fresh muds is the AIT* Array Induction Tool. It measures formation resistivity at five depths of investigation simultaneously—
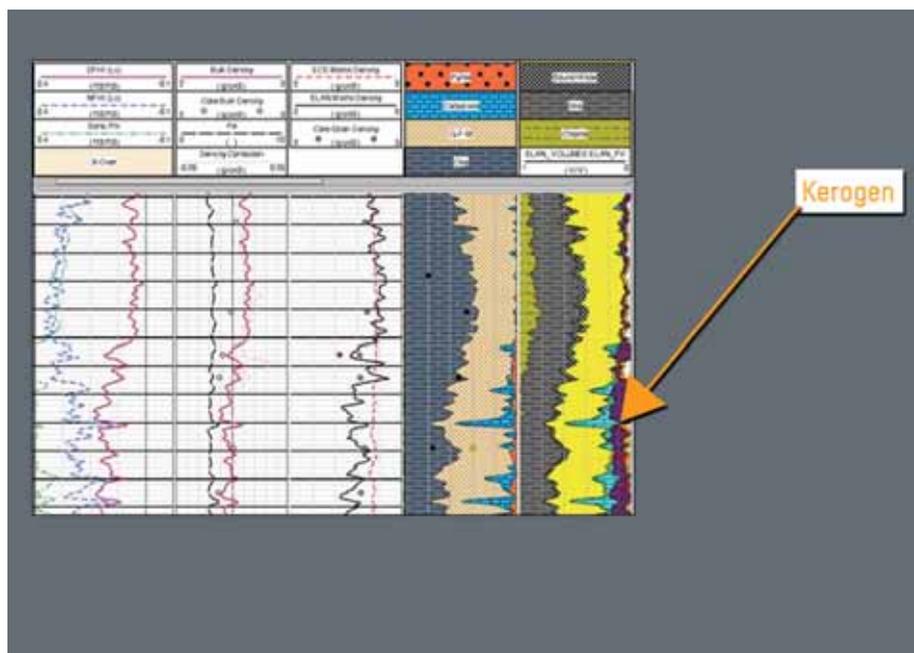

Figure 3: Using ELANPlus software to calculate kerogen volume

10, 20, 30, 60, and 90 inches. In concert with accurate formation porosity, a resistivity measurement permits the quantification of water and gas saturation. In gas shale formations, the Platform Express is used to evaluate the following properties:

- Basic lithology and carbonate differentiation
- Scaling of FMI* Fullbore MicroImager log for fracture aperture estimation
- Kerogen / TOC content when combined with ECS

- Effective and total shale porosity plus gas saturation when combined with ECS
- Estimation of free gas in pores in SCF/ton

FMI IMAGES AND ANALYSIS

The acquisition and interpretation of FMI images, including static and dynamic normalization, facilitates the mapping and orientation of stratigraphic features including bed boundaries, cross-beds and unconformities. It also supports a complete evaluation of faults and fractures that intersect the borehole. Interpretation

includes fracture genesis, open, healed, and drilling-induced; and an estimate of fracture aperture. Stress can be interpreted through orientation of drilling-induced fractures, borehole breakout and borehole ovalization. A geologic interpretation for many of these features is provided on the final log, along with stereonet projections for fracture and bedding orientation.
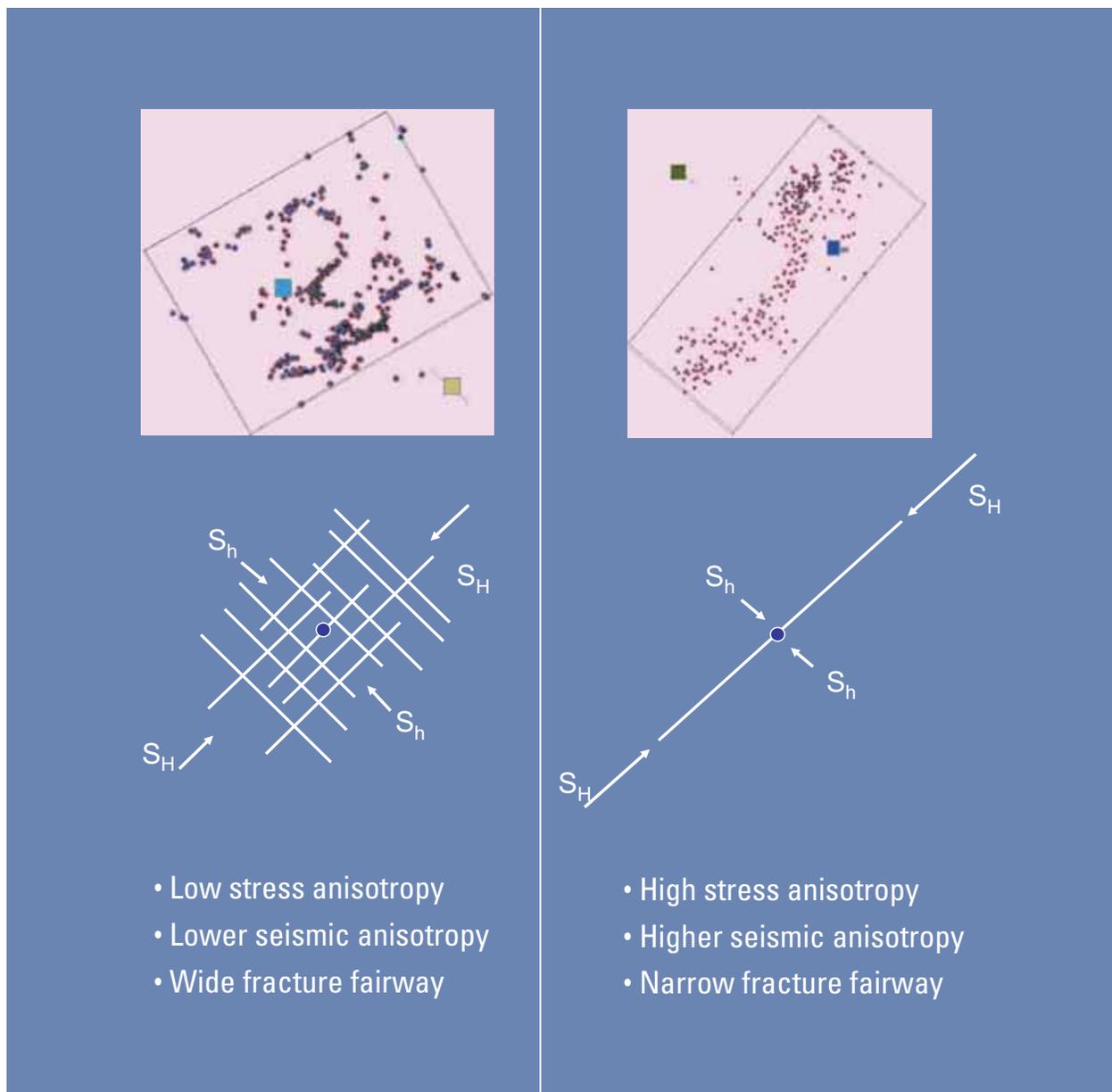

- Low stress anisotropy
- Lower seismic anisotropy
- Wide fracture fairway

- High stress anisotropy
- Higher seismic anisotropy
- Narrow fracture fairway

Figure 4: 3D Sonic Scanner Stress Anisotrophy

CREATING A COMPREHENSIVE PICTURE

Based on the full spectrum of analysis, we produce a total gas log showing total gas, adsorbed gas and free gas (Figure 4). The client can see exactly how much gas is present and exactly where it is, information essential to a sound economic evaluation of a well's long-term potential.

Using our comprehensive, integrated approach, we are now able to identify and quantify a resource that was almost invisible and unquantifiable with conventional logs alone.

EVALUATING RESOURCE PRODUCIBILITY

Once total GIP has been determined, it is essential to develop an accurate estimate of the producibility of that resource. A key input for this estimate is matrix permeability, which in these shales is often extremely low. While conventional logs contribute to this analysis, matrix permeability is most accurately determined through laboratory core analysis.

It is also essential to determine system permeability, which takes into account the presence of natural fractures in the rock. The less permeable the rock matrix, the more important natural fractures can be, and we map these with image tools and confirm them through core analysis. Sonic logs and stimulation mapping with StimMAP also contribute to a more complete picture of formation structures for more effective frac planning and completion design.

Using all of these data as inputs, simulation technology permits the exploration of a variety of stimulation and completion options to judge their impact on producibility.
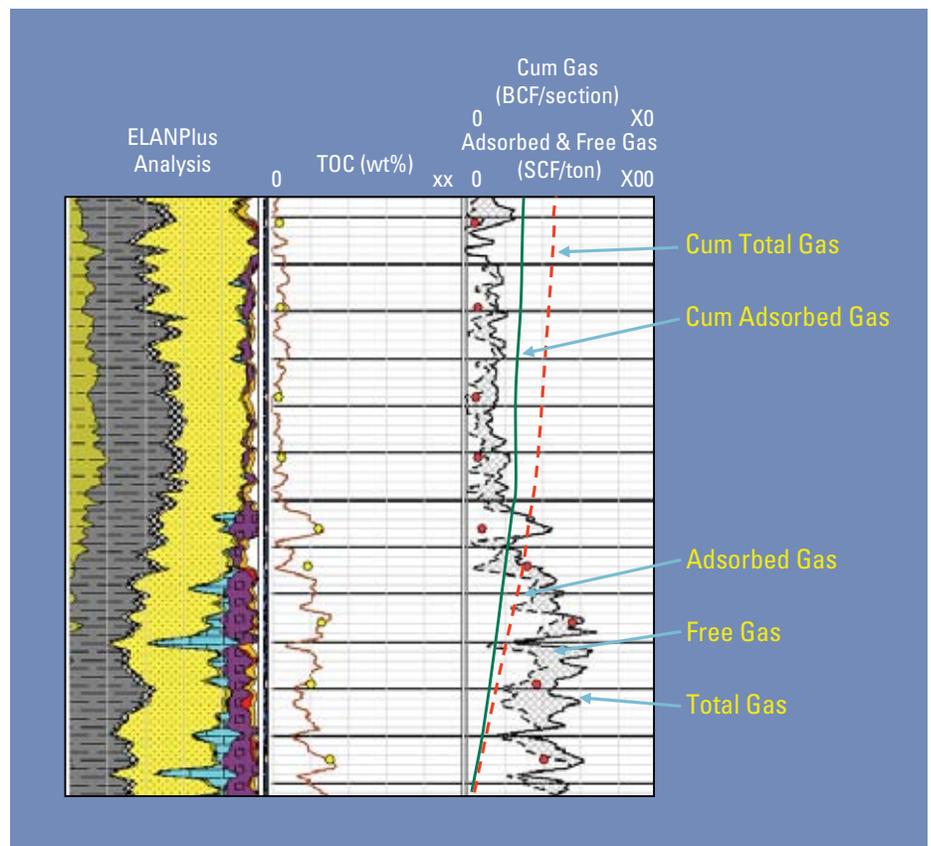

Figure 5: Shale gas adsorption/desorption using Langmuir isotherm equation

CASE STUDIES

Schlumberger is the acknowledged leader in gas shale analysis, with a wealth of successful experience in very challenging field environments.

Schlumberger has been very active in Barnett shale projects, which have established a showcase for the potential of gas shale development and a proving ground for breakthroughs in analytical approach and technologies. One of the first questions a customer often asks about a new prospect will be, "Is it as good as the Barnett?" Schlumberger is in a unique position to answer that question definitively.

In the Lewis shale, in the Four Corners area of the western United States, we developed a 30-year record of production based on history matching, illustrating the value of collecting core data over time. Figure 5 shows cumulative production broken down into its components of free and adsorbed gas. For the first five years, adsorb gas is not significant, but with time it becomes an important factor, in this case 20% of production at 30 years. This information helps the client make better decisions about a well's short- and long-term prospects.

With rising energy prices, many new areas are now being developed, including Project DeSoto, a 900,000-acre lease owned by SEECO. Schlumberger is providing all the logging and evaluation, as well as cementing and completion services, for a planned 185-200 wells in the current year.
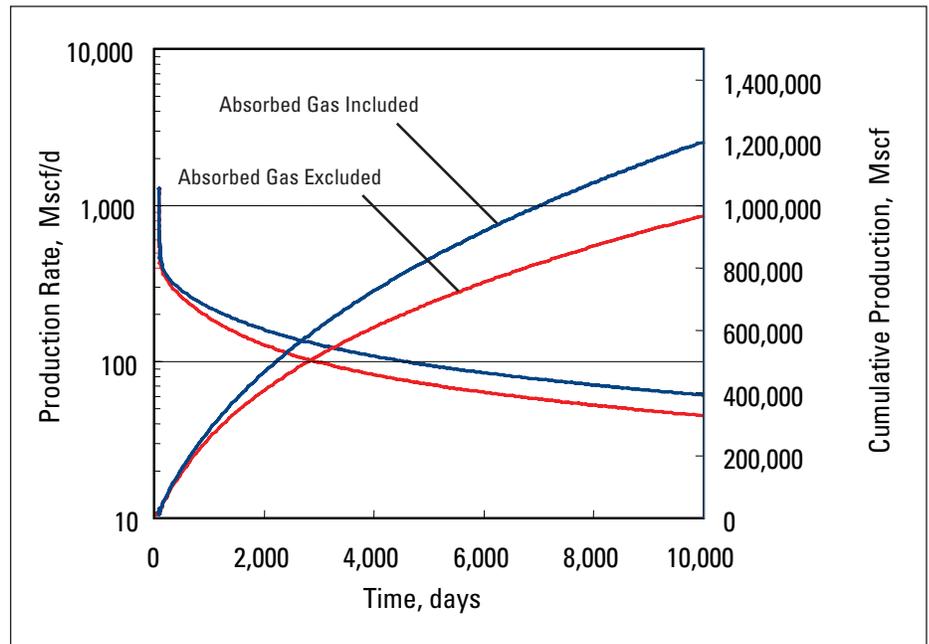

Figure 6: Adsorbed gas impact on late-term production in Lewis Shale

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