[PS]Characterization of Unconventional Shale Gas Reservoirs using a Shale Gas Facies Expert System to Identify Lithofacies and Optimal Completion Intervals*

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Abstract

Unconventional shale gas reservoirs have rapidly gained importance over the past few years in North America as their percent contribution of total gas production has continued to increase. These reservoirs are rather complex and heterogeneous in terms of their geochemical, petrophysical, and geomechanical properties. It is important to identify optimal completion zones for hydraulically fracturing or horizontally completing these reservoirs in order to maximize production rates. The optimal zones are usually chemostratigraphic units or lithofacies that can be identified in shale gas reservoirs using a combination of petrographic, core, and well log analyses techniques. Identification of these lithofacies that may be unique to each shale gas reservoir is crucial for devising completion strategies. These lithofacies are typical geomarkers that usually represent eustatic changes during deposition of sediments and organic matter in these basins. Thus, they are directly related to the preservation and amount of accumulated TOC in the basin. Since gas content is related to TOC, which varies according to lithofacies, identification of these organic-rich lithofacies is important. Some lithofacies (e.g., siliceous lithofacies) are more favorable for gas recovery than others because their mineralogy and TOC content combined with their geomechanical properties make them more conducive to forming extensive fracture fairways. On the other hand, certain lithofacies (e.g., phosphatic lithofacies), based on their geomechanical properties, are fracture barriers and need to be avoided because they act as zones of fracture propagation attenuation.

A shale gas facies expert system was developed with the goal of helping operators identify optimal zones for designing selective completion strategies. This can potentially reduce fracturing expenses and optimize well productivity. The expert system first chemostratigraphically characterizes the reservoir into different lithofacies based on their geochemical makeup obtained from geochemical logging measurements.

Then this system uses an integrated petrophysical reservoir evaluation approach by incorporating multiple openhole logging measurements to flag the most favorable and unfavorable zones using a simple “stop-light” approach.

We present facies models for the Barnett, the Haynesville, the Marcellus, the Woodford, and the Eagle Ford shales applied to a case study well in each of these plays to illustrate this approach.

Characterization of Unconventional Shale Gas Reservoirs Using a Shale Gas Facies Expert System to Identify Lithofacies and Optimal Completion Intervals

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ABSTRACT

Unconventional shale gas reservoirs have rapidly gained importance over the past few years in North America as their percent contribution of total gas production has continued to increase. These reservoirs are rather complex and heterogeneous in terms of their geochemical, petrophysical, and geomechanical properties. It is important to identify optimal completion zones for hydraulically fracturing or horizontally completing these reservoirs in order to maximize production rates. The optimal zones are usually chemostratigraphic units or lithofacies that can be identified in shale gas reservoirs using a combination of petrographic, core, and well log analyses techniques. Identification of these lithofacies that may be unique to each shale gas reservoir is crucial for devising completion strategies. These lithofacies are typical geomarkers that usually represent eustatic changes during deposition of sediments and organic matter in these basins. Thus, they are directly related to the preservation and amount of accumulated TOC in the basin. Since gas content is related to TOC, which varies according to lithofacies, identification of these organic-rich lithofacies is important. Some lithofacies (e.g., siliceous lithofacies) are more favorable for gas recovery than others because their mineralogy and TOC content combined with their geomechanical properties make them more conducive to forming extensive fracture fairways. On the other hand, certain lithofacies (e.g., phosphatic lithofacies), based on their geomechanical properties, are fracture barriers and need to be avoided because they act as zones of fracture propagation attenuation.

A shale gas facies expert system was developed with the goal of helping operators identify optimal zones for designing selective completion strategies. This can potentially reduce fracturing expenses and optimize well productivity. The expert system first chemostratigraphically characterizes the reservoir into different lithofacies based on their geochemical makeup obtained from geochemical logging measurements. Then this system uses an integrated petrophysical reservoir evaluation approach by incorporating multiple openhole logging measurements to flag the most favorable and unfavorable zones using a simple "stop-light" approach.

We present facies models for the Barnett, the Haynesville, the Marcellus, and the Woodford shales applied to a case study well in each of these plays to illustrate this approach.

Need for a Shale Gas Facies Expert System

The complex mineralogical and geochemical properties of shale gas reservoirs, coupled with their low porosities and permeabilities, pose a challenge in predicting the success of drilling and stimulation strategies and economically producing these reservoirs. These challenges arise from the presence of a variety of chemostratigraphic units or lithofacies in these reservoirs that possess varying geochemical, petrophysical and geomechanical properties. A need exists for a shale gas facies expert system that can provide a comprehensive chemostratigraphic characterization of shale gas reservoirs by identifying these lithofacies and utilizing a combination of reservoir formation properties. This can aid operators locate favorable fracturing intervals and/or optimal lateral drilling targets thereby reducing completion costs and optimizing hydrocarbon recovery. A shale gas facies expert system has been developed incorporating an integrated petrophysical reservoir-evaluation approach for characterizing shale gas reservoirs utilizing downhole wireline log measurements. An integrated petrophysical approach enables a comprehensive characterization of the reservoir in terms of its various properties. This approach incorporates a combination of conventional petrophysical measurements, viz., gamma ray, density, neutron, and resistivity, in conjunction with geochemical, acoustic, and nuclear magnetic resonance (NMR) measurements.

CONCLUSION

The shale gas facies expert system provides:

- A simplistic lithofacies determination model to chemostratigraphically classify shale reservoirs
- Operators a quick and accurate method of identifying favorable zones for hydraulically fracturing these reservoirs

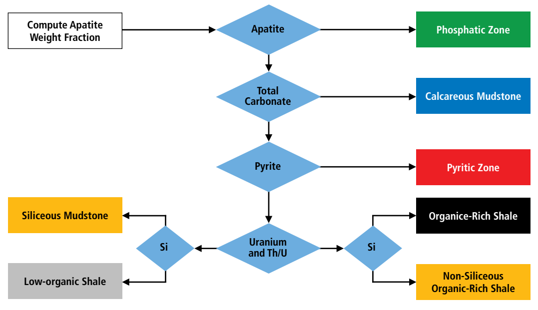
Most shale reservoirs can be chemostratigraphically classified into three primary lithofacies:

- Siliceous mudstone lithofacies
- Organic mudstone lithofacies
- Calcareous mudstone lithofacies
(additional lithofacies are identified based on reservoir properties)

The Shale Gas Facies Expert System

The shale gas facies expert system comprises two components: The chemostratigraphic classification of the shale reservoir into different lithofacies, and the identification and flagging of favorable and unfavorable zones for hydraulically fracturing the reservoir.

The first component of the shale gas facies expert system uses the thorium and uranium measured in the formation in conjunction with the associated mineralogy to classify the formation into lithofacies. The second component of the shale gas facies expert system uses a simple "stop-light" approach to mark zones favorable for fracturing as "green" and unfavorable zone as "red". Zones that are identified as neither favorable nor unfavorable are not flagged and are "white". This flagging is based on zones in the formation satisfying the criteria of the computed lithofacies in conjunction with the TOC content, mineralogy, total porosity, and computed geomechanical properties.



The Shale Gas Facies Expert System determines lithofacies. Example workflow of the Barnett Lithofacies Model

Barnett Lithofacies Model

The Barnett Shale can be distinguished into seven different lithofacies

- Organic-rich shale
- Non-siliceous organic-rich shale
- Low-organic shale
- Siliceous mudstone
- Calcareous mudstone
- Phosphatic zone
- Pyritic zone

Woodford Lithofacies Model

The Woodford Shale can be distinguished into five different lithofacies

- Siliceous mudstone
- Siliceous organic mudstone
- Low-siliceous organic mudstone
- Carbonate mudstone
- Low-organic mudstone

Haynesville Lithofacies Model

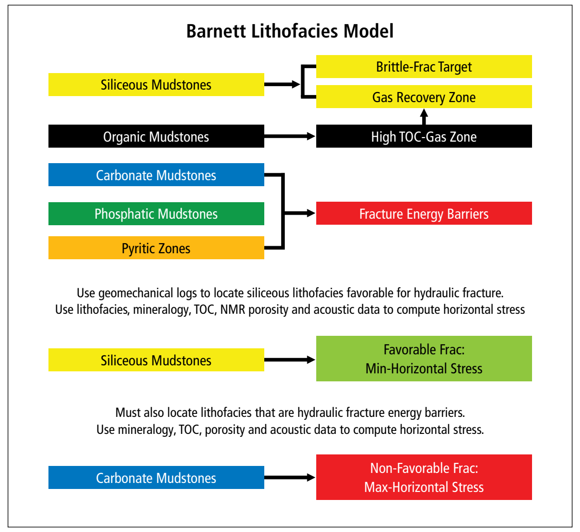
The Haynesville Shale can be distinguished into four different lithofacies

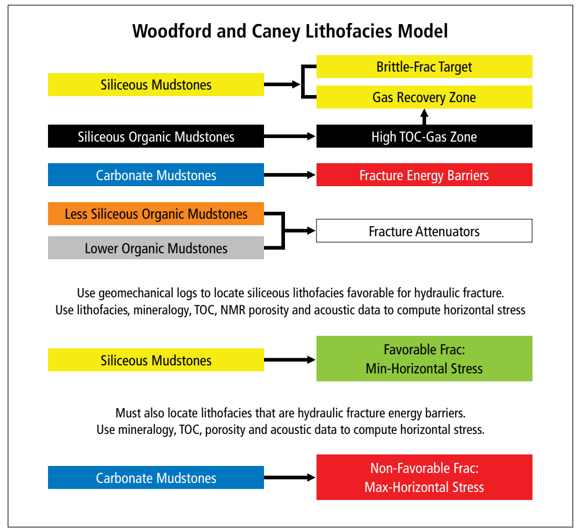
- Siliceous mudstone
- Organic mudstone
- Low-siliceous organic mudstone
- Calcareous mudstone

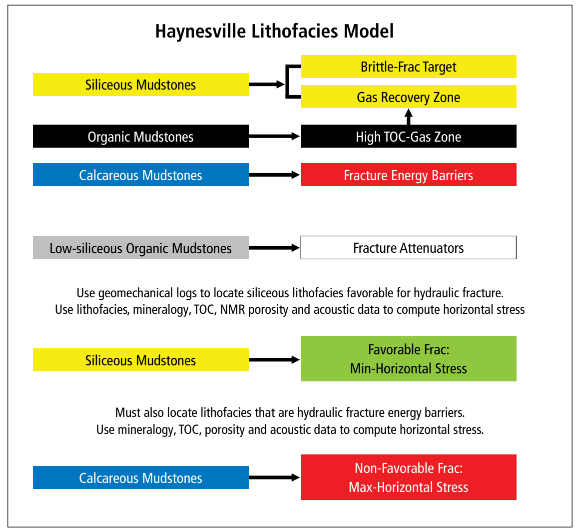
Marcellus Lithofacies Model

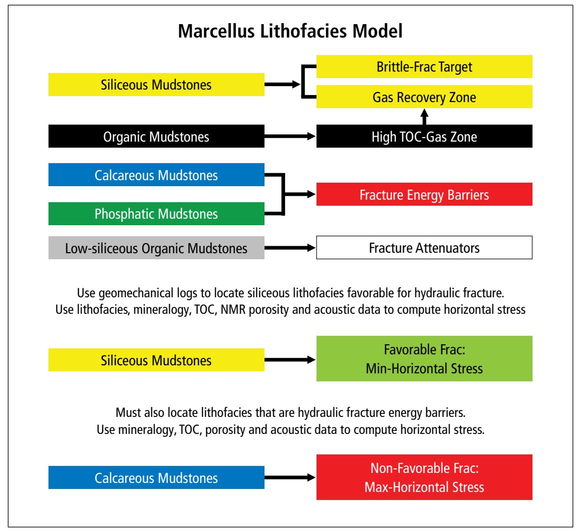
The Marcellus Shale can be distinguished into five different lithofacies

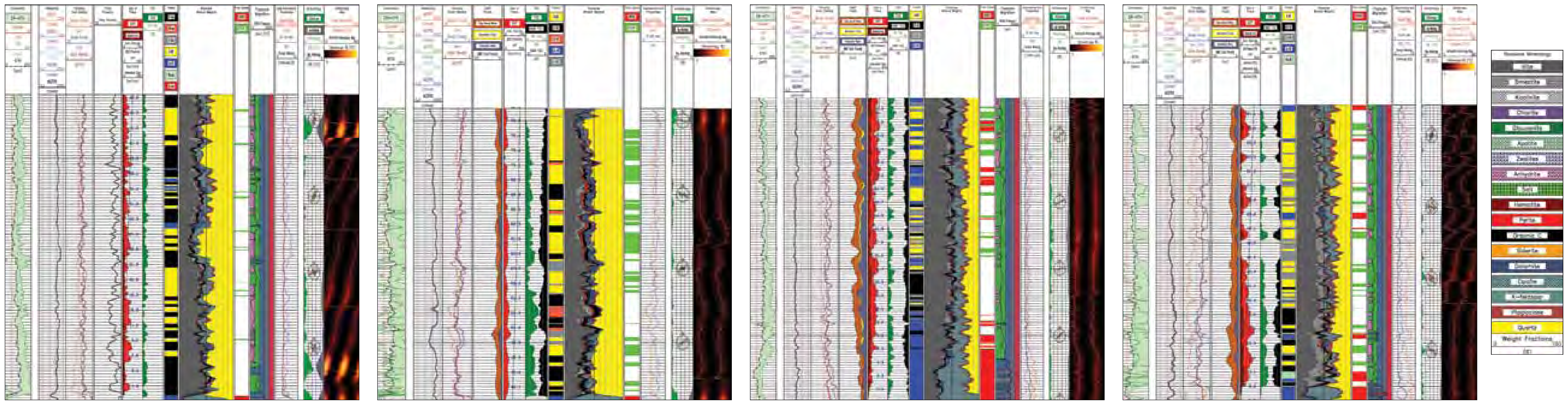
- Siliceous mudstone
- Organic mudstone
- Low-siliceous organic mudstone
- Calcareous mudstone
- Phosphatic mudstone











The figures above show Integrated Shale Analysis plots of a representative well from the Barnett Shale, the Woodford Shale, the Haynesville shale, and the Marcellus Shale, respectively. Tracks 8 and 10 in each figure show the results of the shale gas facies system applied to this well. Track 8 represents the lithofacies determined from each of the individual models and Track 10 represents the "stop-light" component of the shale gas facies expert system, where favorable fracture zones are marked in green and unfavorable fracture zones are marked in red.