Downloaded 11/24/13 to 220.227.148.130. Redistribution subject to SEG license or copyright; see Terms of Use at http://library.seg.org/

Petrophysical Description of Tight Gas Sands

Patricia Castillo, Liwei Ou, Manika Prasad, Colorado School of Mines*

Summary

This paper discusses petrophysical description of tight gas sands formations. We analyze correlations between velocity, permeability, and porosity in three tight sand reservoirs. Flow zone indicator and effective specific surface area methods are introduced to analyze the relations between these properties. Correlations between velocity, permeability, and porosity of clean tight sands are shown to be well characterized after binning the data into zones with distinct effective specific surface or flow zones.

Introduction

Reservoir characterization, an important tool for analyzing production potential of a prospective zone, is challenging in unconventional reservoirs, due to limited understanding of the petrophysical characteristics and the governing factors of flow through these formations. In this paper, we analyze the petrophysical properties and correlations between velocity, permeability, and porosity behavior in tight gas sands.

Tight gas sands (TGS) are considered one of the four designated unconventional gas resources (Hanson and South, 1983). Any gas bearing sandstone that exhibits in situ permeability to gas less than 0.1 md is considered to be a tight formation (Naik, 2003). Although the definition "tight" is based on permeability, these reservoirs are also frequently associated with very low porosities ($\emptyset$< 10 - 12%; Smith et al., 2009). In addition to low permeability and low porosity, other characteristics make TGS more challenging to develop. These formations are characterized by small pore throats range from about 0.03 to 2 µm (Nelson, 2009) and crack-like interconnections between pores. These pore throats represent a small portion of the total porosity but exert a strong control on permeability.

In addition to lesser pore space, the TGS have sutured grain contacts with very little intergranular pores (Spencer, 1997). This difference in texture has significant effects on permeability and the seismic response. At low porosity, if cracks are present, permeability can be enhanced due to better connectivity of the pores; velocity, on the other hand, is lowered because of discontinuities in the acoustic path. As a consequence, relations between permeability and porosity will also carry over to the velocity domain. Thus, seismic properties can become valuable tools to map prospective zones in TGS. On the other hand, when cracks are located inside the grains, velocity values can be significantly lower but the permeability remains the same (Smith et al., 2010). Therefore, a binding criterion based on porosity and permeability might fail in the velocity domain. In this case, it is necessary to find an additional parameter that would allows us to study related properties.

Theory and Methods

We used two methods to analyze the porosity - permeability - velocity correlations in TGS: the Flow Zone Indicators (FZI) method and the Effective Specific Surface (ESS) method. The fundamental use of both methods is to group rocks that have similar flow characteristics defined on the basis of the Kozeny-Carmann relation of porosity and permeability.

The Flow Zone Indicator, as defined by Amaefule et al. (1993), incorporates the geological attributes of texture and mineralogy in the discrimination of distinct pore geometrical facies (Amaefule et al., 1993). Dividing the zones based on their FZI values helps in the identification of high reservoir quality zones and the selection of optimal well locations (Lopez, 2010). The simplified equations of FZI are:

$$\mathrm{RQI} = 0.0314\sqrt{\frac{k}{\emptyset}} \quad (1)$$

$$\mathrm{NPI} = \frac{\emptyset}{(1-\emptyset)} \quad (2)$$

$$\mathrm{FZI} = \frac{\mathrm{RQI}}{\mathrm{NPI}} \quad (3)$$

Where RQI corresponds to the reservoir quality index, k is the absolute permeability in mD, φ is the porosity, and NPI is the void ratio.

Physically, FZI is a product of pore parameters and describes pore connectivity (Prasad, 2003). Its computation is based on tortuous path in a granular bed (Alam et al., 2009), and is proved to have the capability of establishing permeability, porosity and compressional velocity relations in high porosity rocks (Prasad, 2003). Here, we extend the analysis to TGS.

The Effective Specific Surface (ESS) method is based on the definition of a constant c(φ) that accounts for the fraction of porosity that is inactive in a given flow direction (Alam et al., 2009). It is considered to replace the tortuosity term in Kozeny's equation:

$$c(\phi) = \left[4\cos\left\{\frac{1}{3}\arccos(2\phi - 1) + \frac{4}{3}\phi\right\}\right]^{-1} \quad (4)$$

Using permeability and porosity measurements from cores, effective specific surface is computed using equation:

© 2012 SEG

DOI http://dx.doi.org/10.1190/segam2012-1513.1

$$\mathrm{ESS} = \sqrt{\phi c(\phi)}\,\frac{1}{\mathrm{NPI}}\sqrt{\frac{1}{k}} \qquad (5)$$

Experimental Data

In our experiments, three sample sets were measured and one dataset was taken from published work. We measured datasets 1 and 2 on the Mesaverde Formation rocks, specifically the Green River basin and Uintah basin, respectively, and dataset 4 was measured on the Red Forks Formation rocks. Dataset 3 corresponds to data obtained from the Travis Peak Formation (Jizba, 1991).

The permeability and porosity values were measured on oven dry samples using CMS-300. A Beckman porosimeter and the Archimedes method were also for calculating porosity in the samples. All the methods gave similar porosity values with an error range of 1 to 3 porosity units. In addition to core measurement, well log data of datasets 1, 2 and 4 are also analyzed, including Gamma Ray, P-wave velocity and deep resistivity (ILD).

Data Analysis

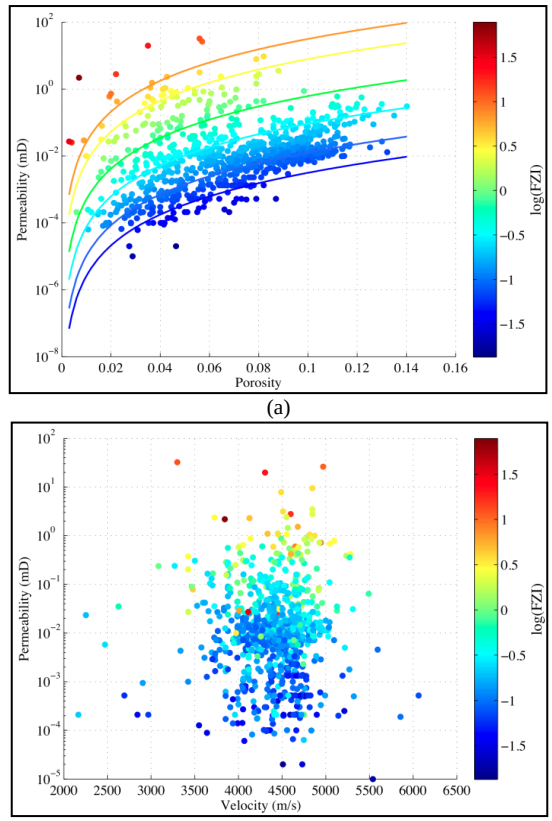
Figure 1 shows porosity-permeability and porosity-Vp plots. We could observe that most permeability-porosity data points are grouped in the range of tight formations. The porosity-Vp crossplot shows that the data points with higher porosity values have a clearer negative trend.

Using the data sets described above we used the FZI and ESS to bin porosity, permeability and velocity values. In Figure 1a, six different zones are distinguished, which have similar flow properties. However, velocity did not show a similar correlation with permeability in distinct flow zones. The data overlap in clusters without any obvious trends, as shown in Figure 1b.

Similarly, when using the ESS method we find that it is possible to group six different zones in the porosity - permeability plot with distinct transport properties, as shown in Figure 2a. However, the velocity-permeability (Figure 2b) shows overlap of data without clean demarcation between the zones seen in Figure 2a. Therefore, we can quantitatively describe permeability knowing porosity and effective specific surface values. Similar to the FZI method, ESS fails to correlate velocity and permeability values. In contrast, Prasad (2003) has shown that high porosity rocks have a distinct velocity-permeability relation within similar flow zones. In the following, we will examine this difference between high porosity rocks and TGS.

Velocity-Porosity Analysis

In order to further understand the physical correlation of velocity and permeability, an additional parameter was used in order to sort the data. We found that high clay content (higher that 25%) samples have lower velocity and porosity values and can easily be separated from clean samples. After discarding data points based on a velocity - porosity behavior criterion and clay content, we found that both FZI and Effective Specific Surface methods effectively describe permeability and porosity relation, as shown in Figure 3. Additionally, in Figure 4 we observe that velocity and permeability correlation can also be fully characterized by FZI and ESS values.



(a)

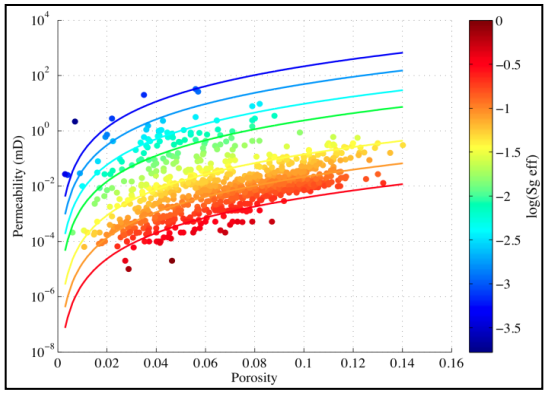
(b)

Figure 1: Figure 3a shows that FZI criterion also helps differentiate in low permeability behavior as a function of porosity. Six different zones are easily distinguished in the plot. The computed FZI values ranged from 3 to 0.05. However, as shown in Figure 3b the extended analysis including velocity does not provide a clear trend separation. The data overlap in clusters without any obvious trends.

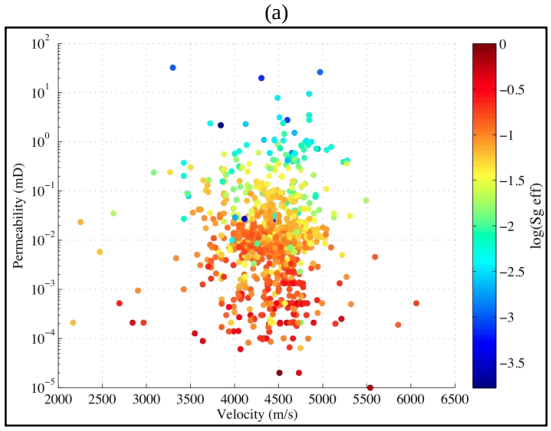
Downloaded 11/24/13 to 220.227.148.130. Redistribution subject to SEG license or copyright; see Terms of Use at http://library.seg.org/

© 2012 SEG

DOI http://dx.doi.org/10.1190/segam2012-1513.1



(a)



(b)

Figure 2: From Figure 2a it is possible to differentiate six zones with similar flow properties based on porosity and permeability values. Nevertheless, when analyzing velocity behavior, we cannot identify any visible trend for the permeability and velocity plot, as shown in Figure 2b.

Discussions

Although both the ESS and the FZI could bin the porosity and permeability values, the velocity – permeability bins were not as straightforward. Our analysis shows the clay could play an important role in the low porosity formations. At low porosities, a small amount of clay can block pore throats and change permeability dramatically. Clay in the contact zones can also decrease velocity considerably (Han et al., 1986), because the contact zones are load bearing. At the same time, clay minerals have higher porosity, so the porosity – permeability – velocity correlations tend to smear out. By taking a cut-off velocity at each porosity, we defined a threshold, and could reach a clear correlation of velocity-porosity-permeability.

Our complete study will demonstrate use of capillary pressure and surface area into the correlation with porosity, permeability and velocity; analysis of the relations of intrinsic properties of clean/shaly tight sands with the well log responses, and define the clean/shaly zone features on well logs with the absence of GR/porosity log.

Conclusions

Our study shows that it is possible to extend correlation of velocity-porosity to velocity-permeability. Such correlations have important implications in understanding permeability variations away from the borehole. We show that:

1. The FZI criterion and Effective Specific Surface criterion can accurately describe permeability behavior as a function of porosity for low permeability and low porosity rocks.
2. Velocity and permeability correlation shows considerable scatter as permeability decreases. Additional information is needed to understand this scatter.
3. By using clay content information as a discriminative criterion, the velocity and permeability relation is much improved in separate flow zones described by the both binning criteria.
4. In absence of lithology information, we can use the porosity - velocity trends as a criterion to identify clean zones. At the same porosity, clay-rich zones will show slower velocities.

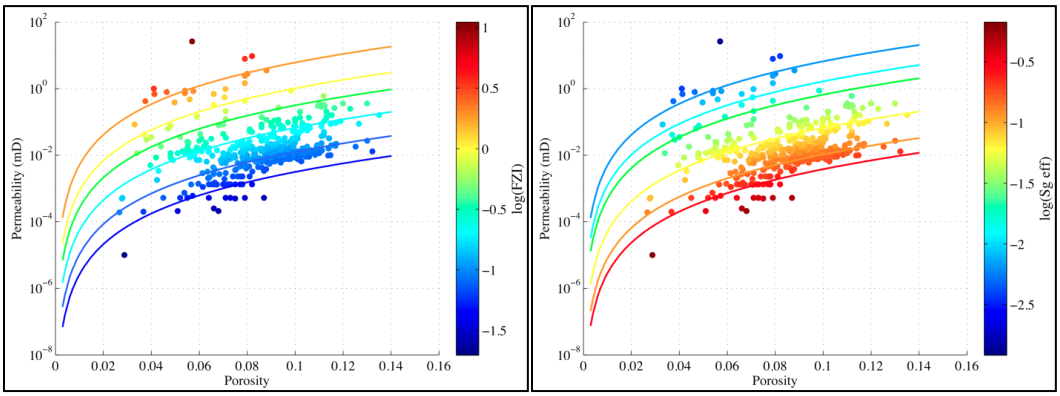
Acknowledgement

We express gratitude to the Fluids Consortium for sponsorship and financial support, Donna Anderson and Dan Friedrich from EOG and Tad Smith for making data and cores available for this study, as well as their input, guidance discussions, and comments.

Downloaded 11/24/13 to 220.227.148.130. Redistribution subject to SEG license or copyright; see Terms of Use at http://library.seg.org/

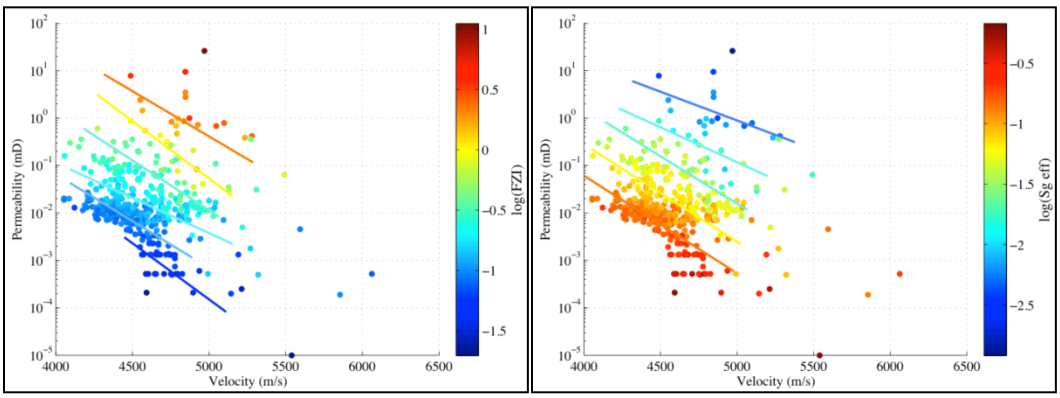
© 2012 SEG

DOI http://dx.doi.org/10.1190/segam2012-1513.1



(a) (b)

Figure 3: Permeability - Porosity relation based on (a) FZI and (b) ESS methods after discarding points with high clay content. Both binning methods accurately characterize low permeability behavior as a function of porosity. Six different zones are easily distinguished in the plot. Computed FZI values ranged from 0.5 to 2.2 while ESS values ranged from $10:5^{-4}$ to 0.25.



(a) (b)

Figure 4: Permeability - Velocity relation based on (a) FZI and (b) ESS methods after discarding points with high clay content. Both binning methods accurately characterize low permeability behavior as a function of velocity. Six different zones are easily distinguished in the plot. Computed FZI values ranged from 0.5 to 2.2 while ESS values ranged from $10:5^{-4}$ to 0.25.

Downloaded 11/24/13 to 220.227.148.130. Redistribution subject to SEG license or copyright; see Terms of Use at http://library.seg.org/

© 2012 SEG

DOI http://dx.doi.org/10.1190/segam2012-1513.1

http://dx.doi.org/10.1190/segam2012-1513.1

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2012 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Alam, M. M., I. L. Fabricius, and M. Prasad, 2011, Permeability prediction in chalks: AAPG Bulletin, BLTN10–172.

Han, D., A. Nur, and D. Morgan, 1986, Effects of porosity and clay content on wave velocities in sandstones: Geophysics, **51**, 2093–2107.

Hanson, D., and D. South, 1983, Western tight sands gas development: Economic and regulatory aspects of blanket-resource supply: Technical Report, Gas Research Institute.

Holditch, S., 2006, Tight gas sands: Journal of Petroleum Technology, **58**, 84–90.

Jizba, L., 1991, Mechanical and acoustical properties of sandstones and shales: Ph.D. thesis, Stanford University.

Lopez, C., 2010, Integrated permeability modeling of the Morrow Sandstone, Hovey Morrow unit Postle field, Texas County, Oklahoma: M.S. thesis, Colorado School of Mines.

Naik, G., 2003, Tight gas reservoirs — An unconventional natural energy source for the future: Association of Petroleum Geologists of India.

Nelson, P., 2009, Pore-throat sizes in sandstones, tight sandstones, and shales: AAPG Bulletin, **93**, 329–340.

Prasad, M., 2003, Velocity-permeability relations within hydraulic units: Geophysics, **68**, 108–117.

Smith, T., C. Sayers, and C. H. Sondergeld, 2009, Rock properties in low-porosity/low-permeability sandstones: The Leading Edge, **28**, 48–59.

Smith, T., C. Sondergeld, and A. Tinni, 2010, Microstructural controls on electric and acoustic properties in tight gas sandstones; some empirical data and observations: The Leading Edge, **29**, 1470–1474.

Spencer, C., 1997, Describing petroleum reservoirs of the future: U. S. Geological Survey, Energy Resource Surveys Program, energy.usgs.gov/factsheets/Petroleum/reservoir.html.

Downloaded 11/24/13 to 220.227.148.130. Redistribution subject to SEG license or copyright; see Terms of Use at http://library.seg.org/