Predicting Fracability in Shale Reservoirs

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The effectiveness of fracture stimulation techniques in increasing the flow of fluids to the well bore in shale reservoirs depends on numerous complex and interdependent factors, each of which can be difficult to predict. Our ongoing research considers four of these factors—lithology, broadly defined to include organic matter and thermal maturity, "fracability", the existing stress field, and pre-existing planes of weakness in the rock. Three premises provide a framework for our investigations. First, rocks are by nature heterogeneous and anisotropic. Second, a large portion of this heterogeneity and anisotropy can be explained and predicted by sedimentologic and stratigraphic models. Third, fracture patterns created in the rock are controlled by a complex interaction of stress, both present-day and that induced by the stimulation technique, and the material properties of the rock. Further, the material properties are constrained by the composition and distribution of minerals, the nature of primary sedimentary lamination and fabric, and the presence and orientation of pre-existing planes of weakness in the rock.

Shale-gas systems commonly consist of large volumes of rock that are regionally extensive and pervasively charged with gas. However, shale-gas systems show significant differences in lithology and other reservoir properties both between basins and within basins. Intrabasinal differences within continuous accumulations account for the indistinctly bound areas of better production termed "sweet spots" by operators. Similar sets of facies have been recognized in the Barnett Shale in the Fort Worth basin by all recent workers (Breyer et al., 2011). Dark, siliceous mudstone to claystone with a matrix of clay minerals and cryptocrystalline quartz is the most common facies in the Barnett Shale in the Fort Worth basin. Two predominantly calcareous facies are next in abundance—laminated argillaceous lime mudstone and skeletal, argillaceous lime packstone. Other, less common, facies within the Barnett include calcareous concretions, phosphatic hardgrounds, accumulations of phosphatic grains, and minor quartz-rich lithologies. Dolomite is present as an early diagenetic phase in the siliceous mudstone facies throughout the basin both as isolated rhombs and as clusters of rhombs that have replaced a significant portion of the matrix. Detailed stratigraphic work in the northern portion of the basin has allowed stacking patterns of lithofacies to be recognized within gamma-ray parasequences that can be identified and mapped in Wise County and the surrounding areas (Singh et al., 2008). Work in the central and eastern portion of the basin has related the geographic and stratigraphic distribution of facies within the Barnett to the location of the depositional site on advancing shale wedges (Monroe and Breyer, 2011). Facies in proximal areas of the wedges differ from facies in distal areas, and facies in axial positions differ from facies deposited on the fringes of the wedges.

Fracability has been associated with the material properties of brittleness (in which the ability to resist a load decreases with increasing deformation) and ductility (in which a material can sustain permanent deformation without losing its ability to resist a load). Even though both brittleness and ductility reside beyond the elastic domain, elastic constants such as Young's modulus and Poisson's ratio are used separately or in combination to infer indices of brittleness and ductility. Strength parameters such as Unconfined Compressive Strength (UCS) and Internal Friction Angle (IFA) have also been incorporated with these constants to further refine indices of brittleness and ductility. Typically Young's modulus, Poisson's ratio, and UCS are calculated from geophysical well logs measurements such as bulk density and acoustic slowness. In most cases, the well logs measurements require the appropriate "rock-physics" fluid and mass substitution before the calculations are performed. Our research follows the same protocol with additional input from a hand-held penetrometer (for UCS estimation) and a micro-rebound hammer (for estimation of UCS and IFA) measurements. Both the penetrometer and micro-rebound hammer measurements are at such a scale to be compatible with detailed petrographic, fabric and total organic carbon data. The penetrometer and micro-rebound hammer measurements are performed at such a frequency as to be reconcilable with the well logs thereby allowing the calibration of petrographic data and indices of brittleness and ductility with log readings.

Rock with a high brittleness index in an isotropic stress field will tend to shatter so as to create pervasive multidirectional linear elastic Mode I tensional cracks when subjected to hydraulic fracture stimulation techniques. With increasing stress anisotropy, the fracturing will tend to be confined to the $\sigma1$-$\sigma2$ plane. If pre-existing planes of weakness exist in the rock and the planes of weakness are favorably oriented with respect to $\sigma1$ and $\sigma3$, high-pressure stimulation fluids will cause the pre-existing planes of weakness to reactivate and fail in shear. Such shear failure will then divert the stimulation fluids from the $\sigma1$-$\sigma2$ plane. Predicting the presence and orientation of pre-existing planes of weakness can be accomplished by integrating the structural history of the basin with rock strength history or can be observed on core and/or borehole image logs.

The research program we are undertaking will integrate qualitative and quantitative data. Qualitative data will come from examining core and thin sections to elucidate composition, fabric and primary sedimentary lamination of the rock along with the presence or absence of fractures and faults. Observations on fractures and faults will include recording their pervasiveness and continuity, noting whether failures are open or healed, determining the mineralogy of the fill if healed, and recording the steepness of the failure surfaces. Focal mechanisms from earthquakes or micro-seismic data and the nature and relative amount of flow-back fluids will also be incorporated in our analysis. Quantitative data will include penetrometer and micro-rebound hammer readings, description of present-day stress field [estimates, using a stress-strength equilibrium stress polygon approach, of the magnitudes of $\sigma1 \geq \sigma2 \geq \sigma3$ and their relationship to overburden stress (σ_V)], maximum horizontal stress (σ_H), minimum horizontal stress (σ_h), and direction of maximum horizontal stress (σ_{Haz}). The dip and strike of pre-existing structures and stress related borehole failures will be determined using borehole image log data. Pressures needed to reactivate pre-existing planes of weakness in shear will be calculated from description of the present-day stress field, the dip and strike of pre-existing planes of weakness, and pore pressure. If successful this program of research should be able to establish a means of calibrating lithology with well log response, establish a correlation between lithology and rock strength, and predict fracability based on these features and the nature of the *in situ* stress field.

References Cited

Breyer, J. A., Bunting, P. J. Monroe, R. M., and Steed, M. B., 2011, Stratigraphic and geographic variation in depositional facies in a continuous shale gas reservoir: The Barnett Shale (Mississippian), Fort Worth basin, north-central Texas, *in* Breyer, J. A., editor, *Shale Reservoirs—Unconventional Wisdom*: American AAPG Memoir, *in press*.

Monroe, R. M., and J. A. Breyer, 2011, Shale wedges and stratal architecture, Barnett Shale, (Mississippian), southern Fort Worth basin, Texas, *in*, Breyer, J. A., ed., *Shale Reservoirs—Unconventional Wisdom*: AAPG memoir, *in press*.

Singh, P., R. Slatt and W. Coffey, 2008, Barnett Shale—unfolded: Sedimentology, stratigraphy and regional mapping: Gulf Coast Association of Geological Societies Transactions, v. 58, p. 777-795.

Figure 1. Following page. Constellation of materials, tools, data and techniques to be used in assessing fracability of shale reservoirs. Clockwise from upper right—core from EOG Resources Two-O-Five #2H, spectral gamma-ray well logs from the Two-O-Five #2H, photomicraph of siliceous mudstone facies in Barnett Shale, SEM-EDAX of clays (image from AAPG Memoir 28), Rock-Eval pyrolisis results for the Two-O-Five #2H, penetrometer and micro-rebound hammer used on core samples, stress analysis from borehole image logs, photomicrograph of sponge spicules in Barnett Shale.


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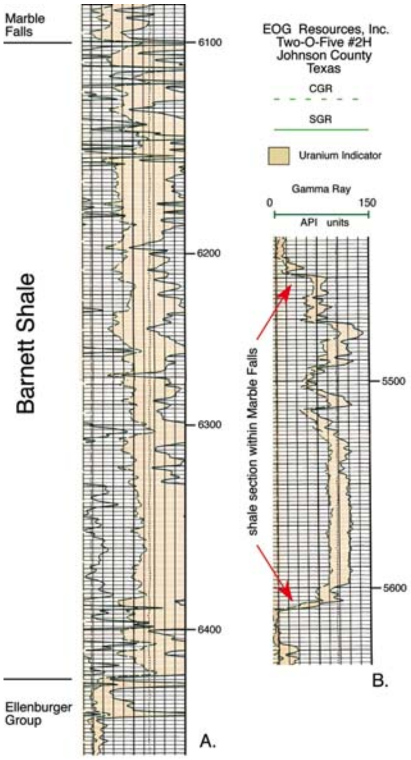
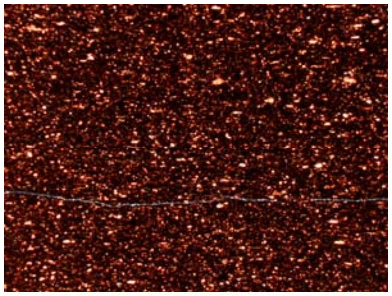
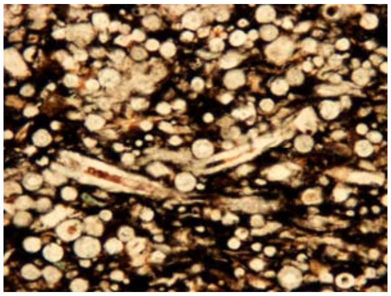
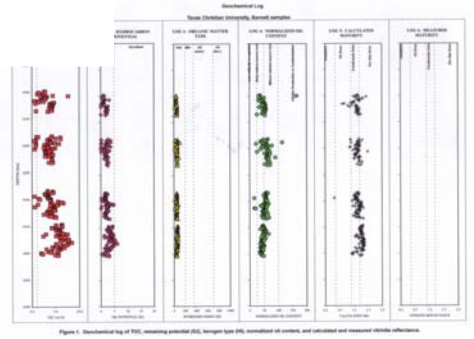
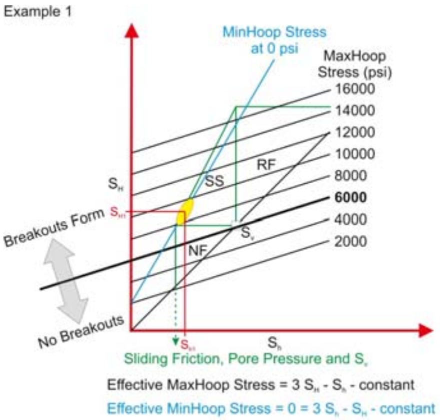
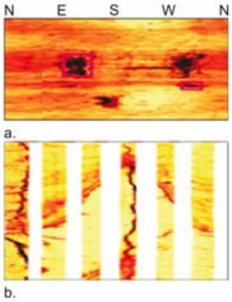

Marble Falls
Barnett Shale
Ellenburger Group
6100
6200
6300
6400
A.
EOG Resources, Inc.
Two-O-Five #2H
Johnson County
Texas
CGR
SGR
Uranium Indicator
Gamma Ray
0
150
API units
shale section within Marble Falls
5500
5600
B.



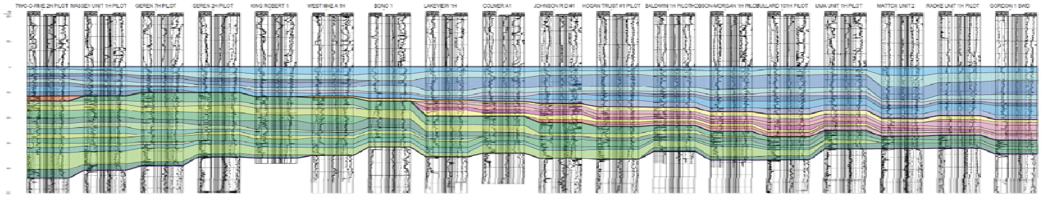



Geochemical Log
Texas Christian University, Barnett samples
Figure 1. Geochemical log of TOC, remaining potential (S2), kerogen type (HI), normalized oil content, and calculated and measured vitrinite reflectance.


Example 1
MinHoop Stress
at 0 psi
MaxHoop
Stress (psi)
16000
14000
12000
10000
8000
6000
4000
2000
RF
SS
NF
S_H
S_H'
S_v
Breakouts Form
No Breakouts
S_H'
S_h
Sliding Friction, Pore Pressure and S_v
Effective MaxHoop Stress = 3 S_H - S_h - constant
Effective MinHoop Stress = 0 = 3 S_h - S_H - constant


N
E
S
W
N
a.
b.


equotip


TWO-O-FIVE 2H PILOT
MASSEY UNIT 1H PILOT
GEREN 7H PILOT
GEREN 2H PILOT
KING ROBERT 1
WEST MHE A 1H
BONO 1
LAKEVIEW 1H
COUNER A1
JOHNSON R D #1
HOGAN TRUST #1 PILOT
BALDWIN 1H PILOT
DOBSON-MORGAN 1H PILOT
BULLARD 101H PILOT
UMA UNIT 1H PILOT
MATTOX UNIT 2
RADKE UNIT 1H PILOT
GORDON 1 SWD