Integration of geomechanical and mineralogical data for fracability evaluation in Utica shale play

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Summary

The Utica shale extends across much of eastern US and as it possesses all the prerequisites of being a successful unconventional play, it has gained attention of the oil and gas industry. The high carbonate content of the target zone enables effective fracture stimulations, but the well performance along the Utica trend is variable; some strong producers are edged out by modest or low producing wells. Each well performance depends on how accurately horizontal drilling and multistage fracturing have been executed in the shale play. The efficiency of fracturing depends on many factors, but brittleness is one of the most important ones. However, there is no universally accepted indicator of brittleness. For the present study, mechanical as well as mineralogical attempts have been made to extract the brittleness information for the Utica play. While an attempt is made to determine brittleness from mechanical rock physics parameters (Young's modulus and Poisson's ratio) derived from seismic data, the available XRD data and regional petrophysical modelling make it possible to determine the brittleness index based on mineralogical data and thereafter be derived from seismic data.

Introduction

Horizontal drilling and multistage fracturing have now made it possible to develop and exploit unconventional reservoirs that were once thought of principally as source rocks. With the successful development of unconventional shale reservoirs worldwide and especially across North America, the oil and gas industry has shifted its attention to a Utica play in Ohio, as its organic richness, high content of calcite, and development of extensive organic porosity make it a potential unconventional play.

Considering the importance of the Utica shale play, a large 3D seismic data volume (1785 km^2) was acquired by TGS in 2015 in eastern Ohio. The primary target zone in the area includes Utica, Point Pleasant and upper Trenton intervals. The Utica interval consists of an organic calcareous shale. The Point-Pleasant (PP) is an organic-rich carbonate interbedded with calcareous shale and underlies the Utica. The upper Trenton interval of the Black river group is an organic-rich carbonate that underlies the Point-Pleasant. Once the Trenton sediment deposition was over, the Point-Pleasant was deposited within restricted-circulation subbasin surrounded by carbonate platforms. The three zones represent a transgressive systems tract where the shallow shelf carbonates of the Trenton were cyclically flooded by the rising seas. A maximum flooding surface is interpreted near the top of Utica shale. Organic content in eastern Ohio is very high and organic matter is very rich and oil prone. Maturity levels created a range of dry gas in the east to oil in the central part of the state. However, the seismic data was acquired over the condensate window. The Point-Pleasant interval is the major producing interval, but the overlying Utica is also prospective.

Brittleness and fracability determination

A successful shale resource play can be identified based on such properties as the maturation, mineralogy, pore pressure, thickness, organic richness, permeability, brittleness and gas in place (Chopra et al., 2012). The present study is limited to brittleness computation while TOC computation has been discussed in a companion paper (Sharma et al., 2017).

Brittleness is a key property that reservoir engineers are interested in as brittle rocks fracture much better than ductile rocks and enhance the permeability. Thus it is desirable for shale source rocks to exhibit high brittleness. The brittleness of a formation is associated with its mineral content (Jarvie et al., 2007). Initially, it was thought that the presence of quartz mineral in a formation makes it more brittle, while more clay makes it ductile. Later, it was observed that the presence of dolomite and calcite tend to increase the brittleness of a shale play (Wang and Gale, 2009). These authors proposed a brittleness index (*BI*) for identification of brittle zones in a shale play as follows:

$$BI_{mineralogy} = \frac{(W_{Quartz}+W_{Calcite}+W_{Dolomite})}{W_{Total}}, \qquad (1)$$

where W corresponds to the weight fraction. Thus, an investigation of different minerals in the zone of interest leads to the identification of favorable drilling zones. Normally, it is an arduous task to compute the individual mineral content of a formation using seismic data, and geoscientists rely on the Young's modulus and Poisson's ratio attributes (Sharma and Chopra, 2015). However, for the present study, the available XRD data suggests that quartz, calcite, and clay are the main minerals present in the Utica play. Additionally, regional petrophysical modeling carried out for the condensate region reveals a strong relationship of clay volume (V_{clay}) with the neutron porosity minus density porosity (NMD) data. Furthermore, the quartz group (quartz + feldspar) and the carbonates group (calcite+dolomite) showed a strong relationship with the neutron porosity curve (NPHI) as shown in Figure 1. Therefore, the volumes of neutron porosity and density porosity (*DPHI*) should be computed so that the mineralogical content of Utica play can be obtained. For doing so first we crossplot both neutron porosity and density porosity with those attributes from well log data that can be seismically-derived. Thereafter, we select those attributes that show a good correlation, so that the relationship could then be used for transforming the seismically-derived attributes into neutron porosity and density porosity. Such a crossplot of these two curves with the measure P-impedance and density over the Point Pleasant interval is shown in Figure 2.

As there is good correlation between P-impedance and NPHI and density and DPHI we can use these respective relationships for deriving both NPHI and DPHI volumes from P-impedance and density volumes. A similar analysis is carried out for the Utica interval and we notice a good correlation between DPHI and density, but a better correlation for S-impedance and NPHI. These determined relationships are then used for deriving NPHI and DPHI volumes from inverted P- and S-impedance and density.

Simultaneous inversion is carried after performing the well-to-seismic tie, prestack data conditioning and low-frequency model building in order to compute the P- and S-impedance from prestack data. This was followed by a probabilistic neural network approach for estimation of density. Blind well tests carried out for P- and S-impedance as well as density enhanced our confidence in the computed volumes as shown in Figures 3a and b. The details of these processes have been shown in a companion paper (Chopra et al., 2017). Next, the determined relationships discussed above were used to transform the inverted attributes (P-impedance, S-impedance and density) into individual mineral content volume. It was noticed here that more than 40% clay content exists in the Utica interval and it decreases as we go from Utica to Trenton. Quartz group content varies from 20-40% for Utica and Point-Pleasant intervals, being higher in the former than the latter. Additionally, carbonate content decreases as we go from Trenton to Utica interval. Thus, the Point-Pleasant interval contains more carbonate content than the Utica interval and seems to be more brittle. This observation matches well with the available petrographic information for the area of study and lends the confidence in the prediction of different mineral content. With these individual mineral volumes now computed, brittleness index attribute was derived using equation 1. A horizon slice from this mineralogical brittleness index volume over the Point Pleasant interval is shown in Figure 4a. Pockets with high values of brittleness are indicated in light blue, dark-blue and magenta colors. The northern part on this display seems to be more brittle, as it exhibits higher values of BI. This observation correlates well with the hydrocarbon production from the Point Pleasant interval, as indicated with the green circles. The data from the peak initial production rate (PIPR) was also available for some of the wells and is overlaid on the horizon slice and seen by the bigger blue circles. Thus PIPR increases as we go from the northern to the southern part of the survey, but the mineralogical index exhibits higher values in the northern part. We explore the reasons for this discrepancy.

Interestingly, the brittleness of a formation is enhanced by carbonates such as limestone and dolomite only up to a volume fraction of about 0.4. Above this value, dolomite and limestone act as fracture barriers as more energy is required to fracture shale rocks with high calcite content (Wang et al., 2012). This could be one of the possible reasons for having lower PIPR in the northern part than the southern within the Point-Pleasant. To understand it a little more, a horizon slice from the computed carbonate content volume is extracted for the Point Pleasant interval and shown in Figure 4b. Notice, more than 40% carbonate content is present over the northern part of the display, i.e. carbonates in this zone could be acting as a fracture barrier. Therefore, mineralogical *BI* computation proposed by Wang and Gale (2009) may not be appropriate for the Point-Pleasant interval. In order to overcome the shortcomings of the mineralogical BI, a fracability index (*FI*) has also been introduced (Jin et al, 2015). Based on the *FI*, high brittleness is not the only criteria for a formation undergoing good fracturing, but the requirement of less energy for creating new fractures is also important. Using the critical strain energy rate and its relationship with fracture toughness (and hence Young's modulus), the mathematical model for FI was proposed as follows:

$$FI = \frac{(BI_{mineralogy} + E_n)}{2}, \quad (2)$$

where E_n is inverse of normalized Young's modulus. Therefore, a formation with higher value of *FI* is considered as a better fracturing target while that with lower fracability is treated as a bad target.

As both the parameters required for *FI* estimation have already been computed, we derive that next. A horizon slice from this volume over the Point Pleasant interval is shown in Figure 4c. Notice, the southern part of Point Pleasant interval shows higher values of *FI* and matches reasonably well with PIPR data which lends the confidence in the whole analysis.

We next turn to making use of mechanical properties of a rock as determined by the Poisson's ratio and Young's modulus, for determination of brittleness of the zones of our interest. Different methods have been proposed for brittleness determination (Mao, 2016), but there is no one universal method that is applicable for all shale formations. We go back to one of the earlier methods proposed by

Grieser and Bray (2007) for brittleness determination within the Barnett shale, using brittleness index (BI), which is a function of Poisson's ratio and Young's modulus, and is defined as follows:

$$BI_{avg} = \frac{E_B+\sigma_B}{2},$$

$$\text{where } E_B = \frac{E-E_{min}}{E_{max}-E_{min}}, \text{ and} \sigma_B = \frac{\sigma-\sigma_{max}}{\sigma_{min}-\sigma_{max}}. \quad (3)$$

Following the above workflow, BI_{avg} was computed using inverted P-, S-impedances and the predicted density. A horizon slice from this volume over the Point Pleasant interval is shown in Figure 5a. Again, it can be noticed here that southern part of the Point Pleasant interval exhibits higher values of BI_{avg} and seems to follow the trend noticed on the similar horizon slice of *FI*. This observation begs the question as to which zone should be considered for further development/drilling within the study area. In order to target a zone, besides brittleness or fracability information, organic richness is another important factor to be considered. The organic richness was determined through TOC content which was derived by transforming the computed density volume. The core-log petrophysical modelling provided the necessary relationship for doing so. A horizon slice generated from the TOC volume over Point Pleasant interval is shown in Figure 5b. Low TOC zones are indicted by yellow and blue colors, whereas black and grey colors represent high TOC zones. Notice that northern part exhibits higher TOC content than the southern part, which is consistent with the prior information available regionally. However, it is also interesting to observe that TOC content over southern part of the Point Pleasant interval is still more than 2% which is a threshold used for identifying a successful shale play as per the organic richness. Consequently, we believe that southern part of Point Pleasant interval must be considered for further drilling in the area of study based on the fact that this zone contains more than 2% TOC with higher *FI* and BI_{avg}, which also shows the consistency with available higher PIPR.

Conclusions

In this study, an attempt has been made to characterize the Point-Pleasant interval of Utica play in eastern Ohio using surface seismic data. Considering the importance of brittleness and its association with mineralogical content of a formation, mineralogical BI was computed. The available regional petrophysical modelling allowed us to determine the volumes of individual mineral existed in the Utica play. A mismatch between higher values of BI and PIPR lead us to conclude that formation with higher brittleness is not always a good candidate for fracking. FI was then used to get a somewhat better idea about favorable fracturing sweet spots. A reasonable match of higher FI values was noticed with higher PIPR which lends the confidence in such a workflow. Thereafter, mechanical properties were considered to identify the brittle zones based on the BI_{avg}. A resemblance was noticed in identifying the favorable zones for drilling based on *FI* and BI_{avg}. Further, TOC volume was brought into the analysis and it was concluded that the whole Point-Pleasant interval could be treated organic-rich. Thus, zones with higher *FI* and BI_{avg} should be considered for further development in the area of study.

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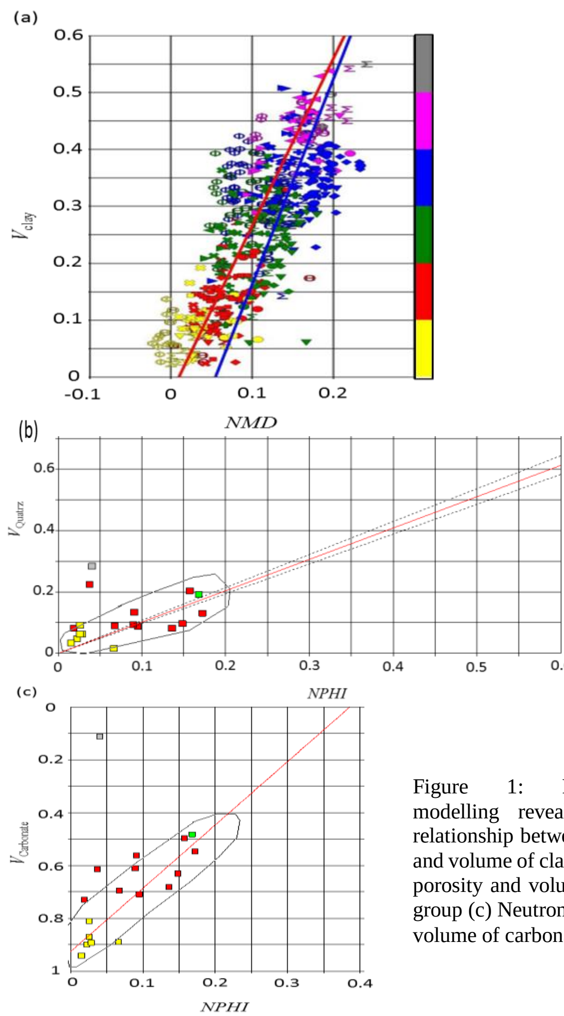

Figure 1: Petrophysical modelling reveals a strong relationship between (a) NMD and volume of clay (b) Neutron porosity and volume of quartz group (c) Neutron porosity and volume of carbonate group.

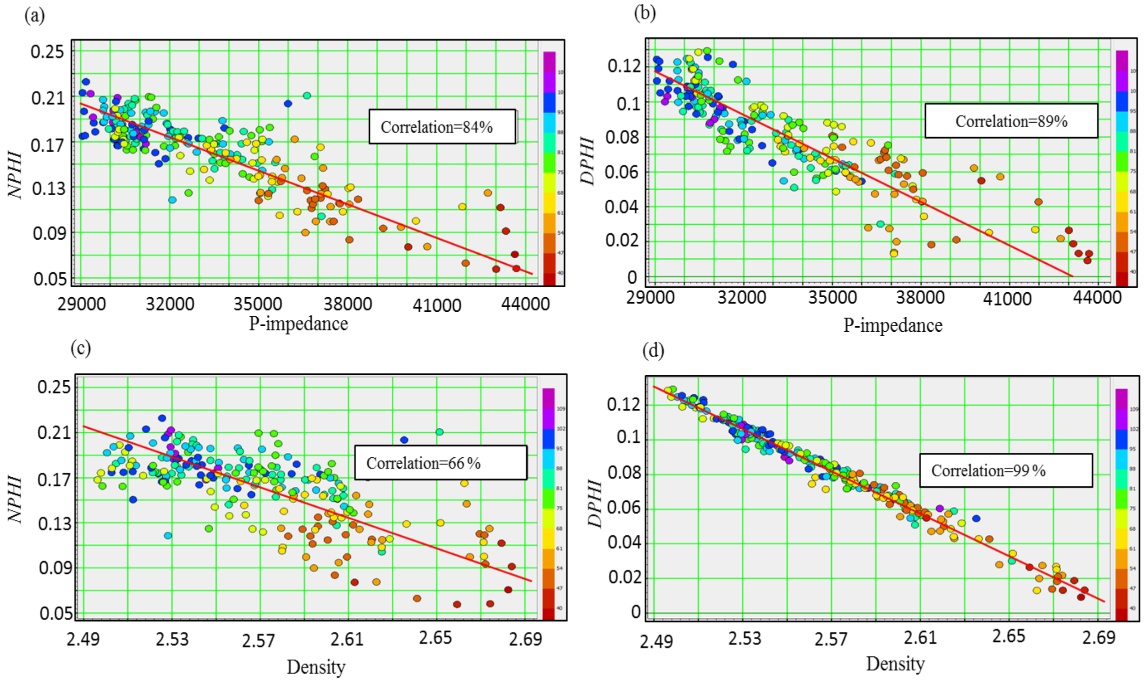

Figure 2: Crossplot of P-impedance versus (a) neutron porosity (b) density porosity, and density versus (c) neutron-porosity and (d) density porosity, over the Point-Pleasant interval. For this interval, we conclude that P-impedance volume can be used to predict NPHI, and the density volume can be used for prediction of DPHI. (Data courtesy: TGS, Houston)

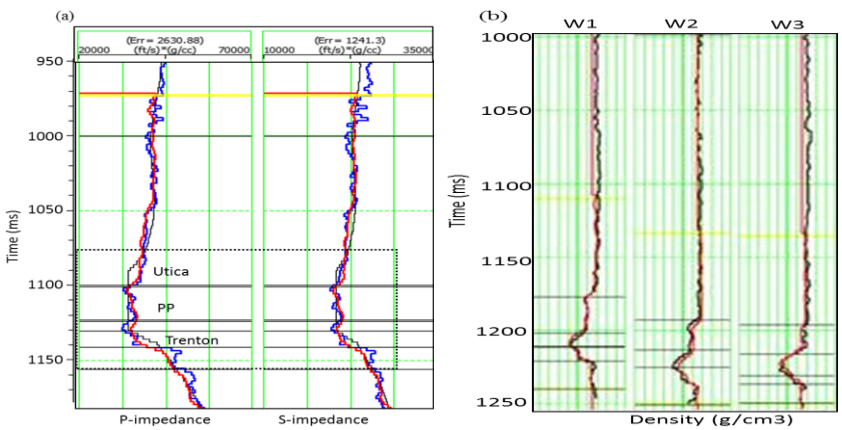

Figure 3: (a) Blind well testing for simultaneous inversion. A very good match between inverted (red) and measured (blue) P-impedance (left track) and S-impedance (right track over the zone of interest) lends confidence to the inversion. (b) Prediction of density at different well locations using supervised neural network approach. Validation analysis showed a correlation of 93%, which is promising. (Data courtesy: TGS, Houston)

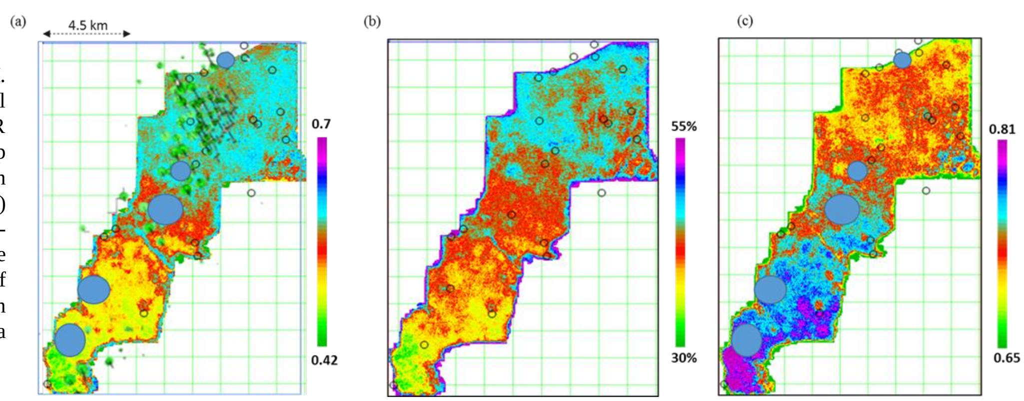

Figure 4: Horizon slices from (a) mineralogical BI. Available production data (green dots) match well with the area of higher BI, however, available PIPR (blue dots) seems to exhibit a reverse relationship with BI, as seen by the size of the blue dots, which corresponds with the numerical values of PIPR; (b) predicted volume of carbonate over the Point-Pleasant interval. Notice, more than 40% carbonate content is seen to exist over the northern area of Point Pleasant; (c) fracability index (FI) where high PIPR seems to match with high value of FI. (Data courtesy: TGS, Houston)

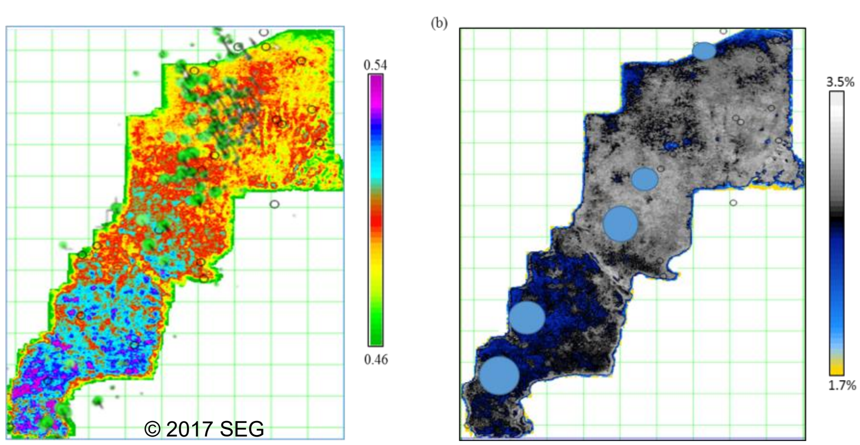

Figure 5: Horizon slices from the (a) computed BI_{avg}, (b) predicted TOC volume in the zone of interest. BI_{avg} follow a trend similar to that of *FI*. Higher values of BI_{avg} are correlating reasonably well with the higher values of PIPR. However, threshold value of TOC used to identify the organic-rich parts reveals that the whole Point Pleasant interval can be considered a as shale play. Thus, pockets with the high *FI* and high BI_{avg} must be considered for further drilling. (Data courtesy: TGS, Houston)

EDITED REFERENCES

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