[GC]Organically-Rich Sweet Spot Determination in Utica Shale*

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General Statement

Utica Shale is one of the major source rocks in Ohio. Its organic richness, high content of calcite and development of extensive organic porosity make it an attractive unconventional play that has gained the attention of the oil and gas industry. The primary target zones in the Utica trend include the Utica, Point Pleasant and Trenton intervals.

In this article, we demonstrate the identification of organically rich sweet spots within the Point Pleasant interval using 3-D seismic data, and the available well and core data. The organic richness is determined through the TOC (total organic carbon) content, which is determined from the available core samples in a well. The measured density log and these TOC values are cross-plotted to derive a relationship between them, which is then used to transform the inverted seismic density volume into a TOC volume. As the available seismic data did not have the long offsets (angles) required for determination of density from prestack simultaneous impedance inversion, neural network approach was followed to compute density using seismic data. The correlation of the TOC sweet spots identified based on the seismic data with the available core data emphasizes the aspect of integration of seismic data with all other relevant data.

Sweet Spot Determination

The main goal for shale resource characterization is usually the identification of sweet spots, which can represent favorable drilling targets. Such sweet spots are zones and areas in the target formation that exhibit high total organic carbon (TOC) content, high porosity, as well as high brittleness or fracture toughness measures. The organic richness in the shale rocks influences properties such as compressional and shear velocities, as well as density. Therefore, attempts have been made to detect variation in TOC from the surface seismic response using impedance and other attributes such as VP-VS ratio, Lambda-rho, Mu-rho, etc.

In this study, the density and TOC measurements made on the core samples in the Point Pleasant interval were cross-plotted as shown in Figure 1. A strong linear relationship is seen between them. This suggests that the density attribute would be required if the organic rich zones in the

Point Pleasant interval are to be determined from seismic data. Once that is obtained, TOC volume could be computed using the determined relationship from the cross-plot.

As stated above, because the offset/angle of incidence range was not favorable for computing density from seismic data through simultaneous inversion, we turned to neural network analysis for its determination. There are two aspects to our motivation for the use of neural network method here. The first has to do with the fact that there were more wells located on the 3-D survey that had the density log curves available, and so could be used in the neural network analysis. The second aspect has to do with the generation of robust low-frequency models that can be generated. For more details on simultaneous inversion, please see Prestack Impedance Inversion Aids Interpretation, Search and Discovery Article #41664, and for low-frequency models, please refer to Finding a Better Path to Impedance Inversion, Search and Discovery Article #41722.

Even though other methods exist that could possibly use a non-linear minimization of error approach, their applications are still not common. Therefore, we decided to determine density with probabilistic neural network analysis, employing amongst others some of the attributes determined from simultaneous inversion.

Density Prediction Using Neural Network Approach

The probabilistic neural network (PNN) implementations have been applied to a variety of geophysical problems. In such an approach, anon-linear relationship is determined between seismic data as well as its various attributes and petrophysical properties. The determined relationship is then used to predict the desired properties away from the well control. For the present study, a multi-attribute linear regression and PNN are implemented to predict the density volume for estimating the TOC volume. We first derive the relevant attributes for our study by applying a prestack simultaneous inversion to conditioned gathers using partial-angle stacks, a reliable low-frequency model and angle-dependent wavelets. The attributes derived from the simultaneous inversion are P-impedance, S-impedance, Lambda-rho, Mu-rho, E-rho, and Poisson’s ratio volumes. A combination of these different attributes is the input to the multi-attribute regression and PNN process to predict density.

An important aspect of this method is the selection of seismic attributes to be considered in the neural network training. To that effect, a multi-attribute stepwise linear regression analysis is performed using the available uniformly distributed wells. An optimal number of attributes and the operator length are selected using the cross-validation criteria where one well at a time is excluded from the training data set and the prediction error is calculated at the excluded well location. The analysis is repeated for all wells, each time excluding a different well. An operator length of nine samples exhibited the minimum validation error with six attributes, namely Poisson’s ratio, E-rho, relative impedance, absolute P-impedance, S-impedance and a filtered version of the input seismic data. Using these attributes, the PNN was trained. A correlation of 98.12 percent was noted between predicted and measured densities at the well locations. After training, a validation process was followed, which showed a correlation of 93.59 percent at the well locations. Such a match enhanced our confidence in the analysis of density prediction. A variation of density values within the zone of interest was noted as we go from the northern to the southern side of the 3-D survey. In figure 2a we show how the predicted density compares with the measured density at the location of well W-7. The good match between the curves enhanced our confidence in this approach.

Density/TOC Transformation

Once the density volume was determined from neural network analysis, the next step was to use the linear relationship shown in Figure 1 to transform it to a TOC volume. We first transformed the density trace at the location of the well wherefrom we received the TOC data determined from the core samples. In Figure 2b we show the match between predicted TOC and that measured from the core samples. A reasonable match between them endorses the relationship, which is then used to transform the predicted density volume into a TOC volume. An arbitrary line passing through the different wells on the 3-D seismic volume is shown in Figure 3a. High TOC content is noticed in the northern part of the survey, which is consistent with TOC trend observed in the Utica-Point Pleasant play.

To map the variation of TOC content laterally, a horizon slice from its volume over a 10 millisecond window in the zone of interest is generated as shown in Figure 3b, low TOC zones are indicated by yellowish and bluish colors, whereas black and grey colors represent high TOC zones. Note that the northern part of the survey exhibits a higher TOC content than the southern zone, which is consistent with the prior information available regionally and matches the available production data.

As the state reported data is not as detailed as required for this type of correlation, it is not being shown here. However, the match seemed convincing.

Conclusion

In conclusion, when the density and TOC values are measured from core samples in the shale interval of interest, they can be cross-plotted to determine a relationship between them. As density is an attribute that can be determined from seismic data, it can then be transformed into a TOC volume using the relationship determined from the core samples. Appropriate tests may be carried out to check the accuracy of the predicted attribute, which if found satisfactory, should also correlate with production data.

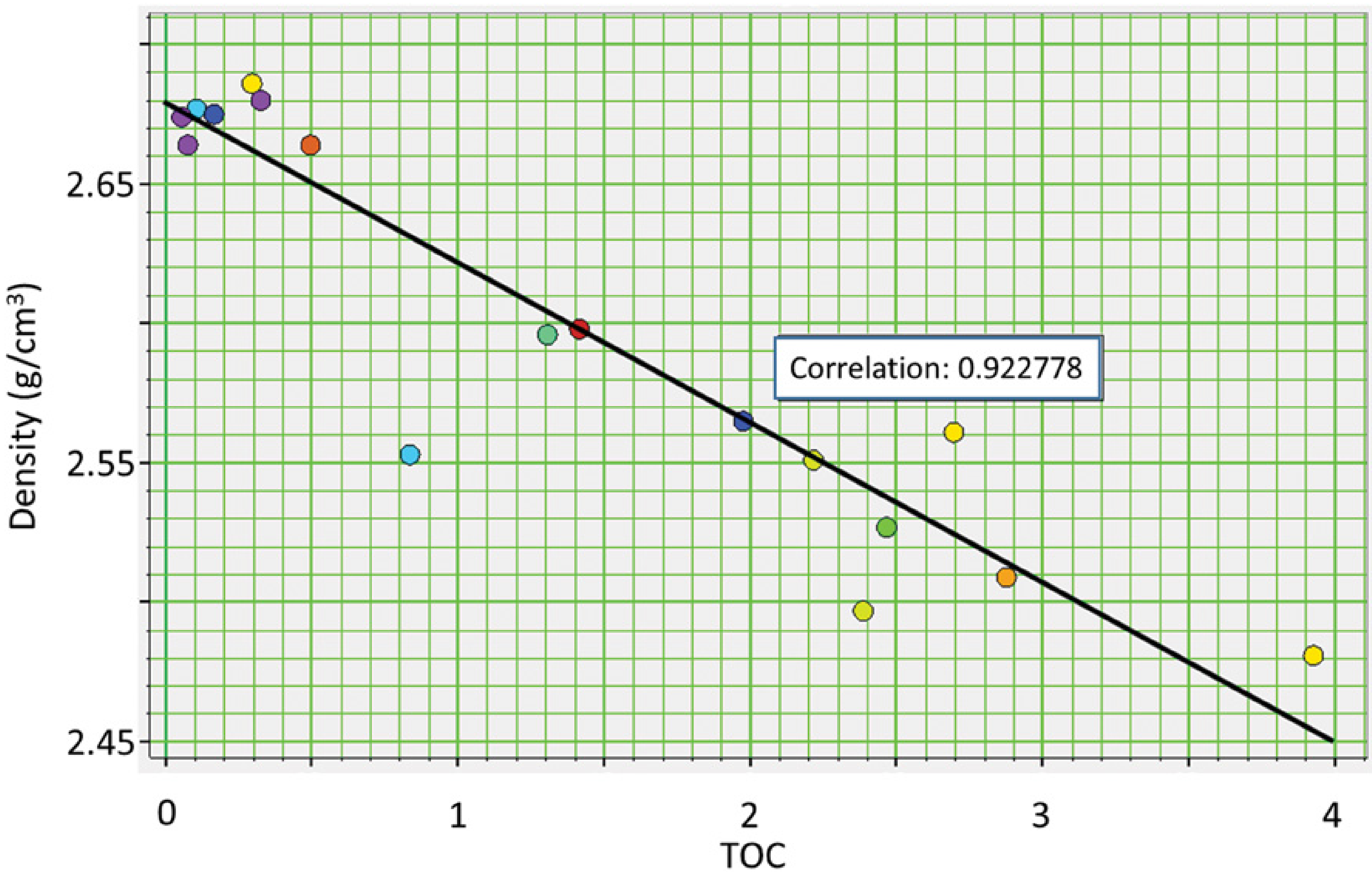

Figure 1. Cross-plot between measured log density and TOC as determined from core data in the Point Pleasant interval.

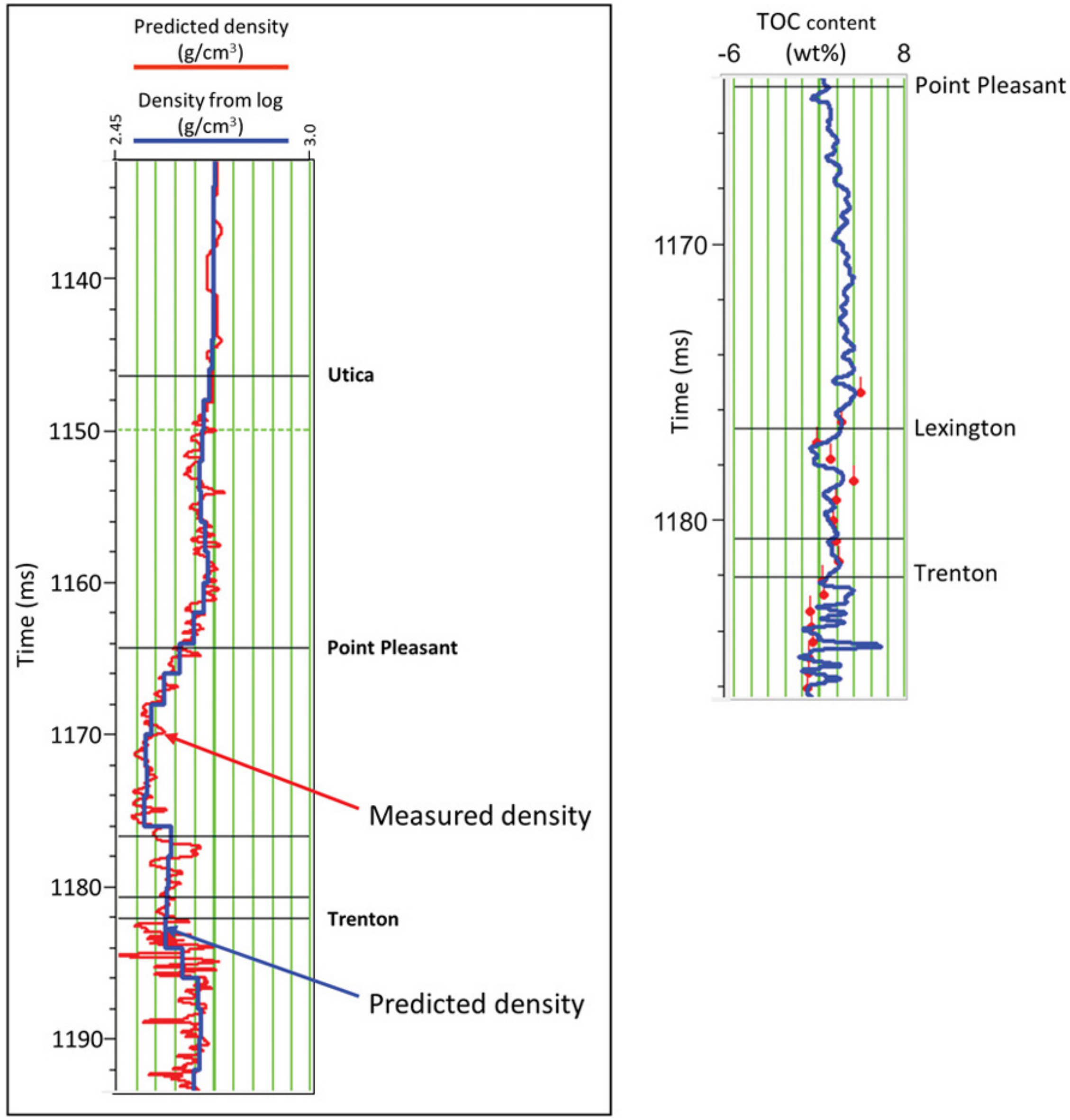

Figure 2. (a) The density trace predicted with neural network application compared with the measured density log curve at the location of well W-7. The two curves overlay well and thus enhance our confidence in neural network density prediction. (b) The neural network TOC predicted curve for the well wherefrom the core samples were available. The red dots are the TOC determined from the core samples. A reasonable match between the two is seen, and thus enhances our confidence in the used approach.

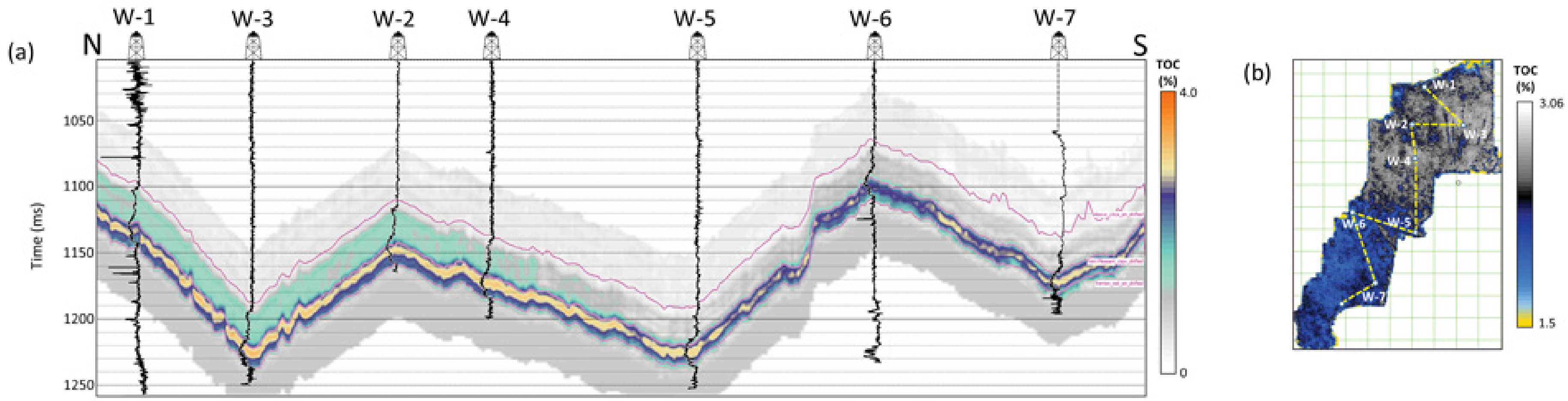

Figure 3. (a) An arbitrary line from the TOC volume and passing through wells W-1 to W-7. (b) A horizon slice at the Point Pleasant level from the TOC volume. The path followed by the arbitrary line through the different wells is also indicated. The TOC content appears to be more on the northern side of the line and gradually decreases to the southern side, even though the TOC values displays are between 2 and 3 everywhere on the display, which are favorable. (Data courtesy: TGS, Houston)