STORY NUMBER: 3-3M , T1, A2
STORY SLUG: Shales/Marcellus 3-D
AUTHOR: CC

Logs Reveal Marcellus Sweet Spots

By Pete Dotsey

HOUSTON–Sweet spots in the Marcellus gas shale trend are being mapped by performing geologic and petrophysical evaluation and interpretation of well log data. Log data for more than 18,000 wells within the trend are being used.

Many authors have indicated that total organic carbon (TOC) and porosity are good indicators of gas shale potential. TOC sample data and log curve data from previously drilled wells are needed to calculate a TOC-calibrated model. Public domain TOC sample data are available from state and federal geologic agencies for many wells within the Marcellus trend. TOC analytical results are needed to calculate porosity.

The gas shale thickness can be determined by interpreting the log curve data for each well, and the areal extent and thickness of the gas shale can be mapped by using all the interpreted wells. Sweet spots can be delineated by mapping calculated TOC and porosity with respect to gas shale area and thickness. The sweet spots are evaluated with respect to gas shale production. This approach has been implemented in several steps:

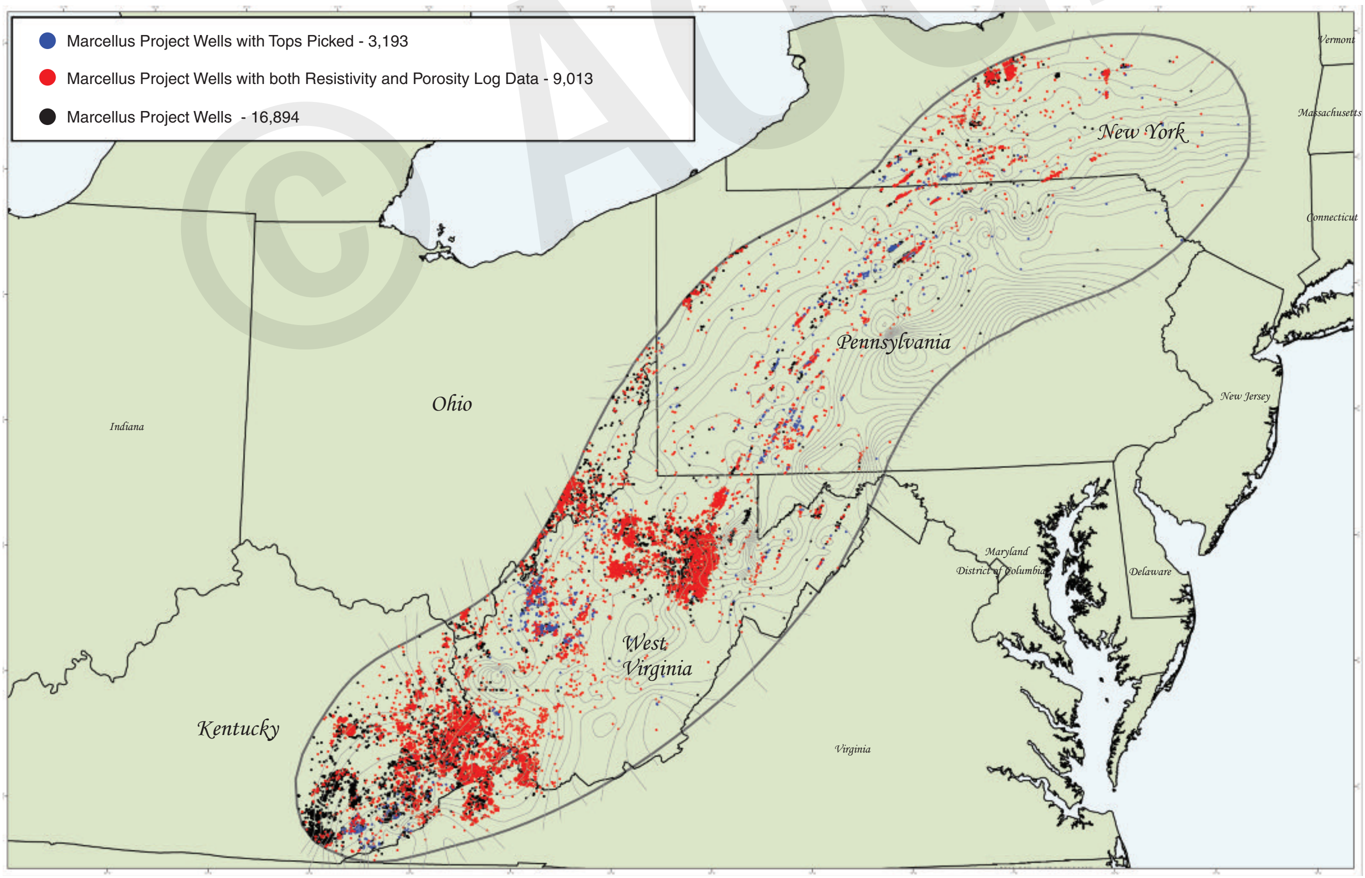
- Identify the Marcellus interval in Marcellus trend wells;
- Digitize well curve data for the identified wells;
- Source available Marcellus well TOC sample data;
- Develop a calibrated TOC model to calculate TOC curves;
- Calculate TOC and porosity for the Marcellus interval in trend wells;
- Correlate and map the geological and petrophysical results throughout the trend; and
- Utilize released production data to validate the geological and petrophysical maps.

Identify The Marcellus Interval

The first step was to identify the Marcellus interval in wells located in the

FIGURE 1

Appalachian Basin Wells with Marcellus Shale Log Curve Data



A shale formation that was described in the very first geological survey conducted in Pennsylvania in 1836 is driving booming upstream and midstream activity in the same basin where the nation's first oil and natural gas wells were drilled. Stretching 600 miles across the Appalachian Basin and covering millions of prospective acres from New York to Virginia, the Marcellus Shale formation is estimated to contain as much as 500 trillion cubic feet of natural gas–enough to supply the entire U.S. market for nearly two decades! Log curve data are available for nearly 17,000 wells that have penetrated the Devonian-age shale. The well locations with tops are shown here, along with the measured depth contours to the top of the interval based on mapping the Marcellus Shale's areal extent and thickness in 3,193 wells.

Marcellus trend. Marcellus regional structure and trend area maps generated by the United States Geological Survey were used at project startup. Within the trend, 275,000 wells have been drilled, but it was not known how many of these wells had penetrated the Marcellus Shale. Well curve data for an initial list of 9,349 wells were loaded into the interpretation project. These wells were geologically evaluated to determine which ones penetrated the Marcellus Shale.

As a result of the geologic evaluation, tops were interpreted in 3,193 wells. Tops were interpreted for the Marcellus Shale, the underlying Onondaga Limestone and the overlying units, which include the Rhinestreet and Genesee shales. The Marcellus Shale is composed of three members: an upper and lower shale member and a middle Cherry Valley Limestone member. All three units are not present throughout the entire trend. Of the 3,193 wells that were interpreted, the upper Marcellus Shale member was present in 1,644 wells, and the lower Marcellus Shale was present in 2,921 wells.

During the well top interpretation exercise, 3,529 wells were eliminated from the initial list of project wells because the Marcellus interval was either not present or not logged in those wells.

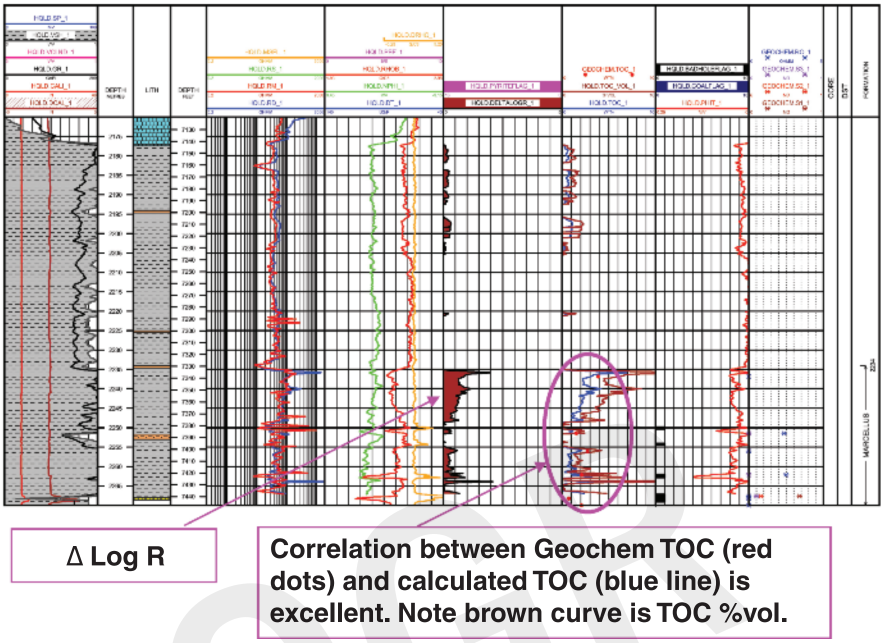
Next, a measured depth map to the top of the Marcellus was generated based on wells for which tops were interpreted. After that, the measured-depth contoured intervals were cross-referenced with the total drilled depth of the 275,000 wells from the database that fell within the trend.

An additional 11,074 wells were identified that should have the Marcellus Shale interval present. These additional wells will be used in the geological and petrophysical evaluation of the trend. This is an ongoing and iterative process. As the Marcellus interval is picked in more wells within the trend, more detailed maps are being made to further cross-reference the database and eliminate wells with insufficient well log interval coverage.

At the time of writing, 16,894 wells had log curve data to map the area and thickness of the Marcellus. These wells are shown in Figure 1. Also shown in Figure 1 are the locations of the wells with tops and the measured depth contours to the top of the Marcellus interval, which are based on mapping the initial 3,193 wells.

Following the interpretation of tops for wells in the Marcellus Shale trend, geological structure maps and bore hole thickness or isopach maps were made for the Marcellus Shale, the Marcellus Shale members, the underlying Onondaga formation and the overlying formations, which include the Rhinestreet and Genesee shales. By utilizing the tops and maps that have been generated, geoscientists will know from anywhere within the trend how far they need to drill to intersect the top of the Marcellus and how much farther they will have to drill to penetrate the entire Marcellus section.

FIGURE 2



Total organic carbon can help map gas shale sweet spots. Using TOC sample data and porosity log curve data, TOC curves have been developed for wells in the Marcellus Shale trend. As data from one well show, the curves accurately predict actual TOC values.

Digitize Curve Data

Once a well is identified that penetrates the entire Marcellus section, the log curve data are digitized. The additional digital well log data then are used for geological and petrophysical evaluation.

The next step in the process, and the first step in generating a calibrated TOC model, is to obtain TOC sample data for the Marcellus interval. As stated above, TOC analytical results are considered to closely correspond with gas shale productivity, or sweet spots, in the trend.

There are several ways to obtain TOC sample data. One is to drill wells and analyze the core and/or cuttings from the well bore. Another way is to review the literature and the Web for TOC sample data results. A third way is to have operators contribute their sample data for review and evaluation. The latter two methods are being used.

After extensive research, TOC sample data were obtained for the Marcellus interval for 93 wells, and 67 of those wells fell within the active Marcellus trend.

Develop A TOC Model

The next step was to develop a TOC model that could be used to calculate a TOC curve for the Marcellus interval. Several approaches for calculating a TOC curve for the Marcellus interval were evaluated. After reviewing the literature and evaluating the available data for relevant wells–that is wells that had both TOC sample data and porosity log curve data–the Passey approach was selected.

The Passey method has four distinct advantages for use in the Marcellus:

- It worked well; that is, the calculated TOC curves pass through the TOC sample points in the well.
- It allows TOC curves to be generated for the wells with the requisite porosity and resistivity log data.
- There are 9,013 wells identified in our database that have porosity and resistivity log data for the Marcellus interval in the Marcellus trend.
- Analyzing these wells should provide a sufficient number of data points to accurately map the sweet spots.

The wells with both porosity and re-

TABLE 1

EQUATION 1: $\Delta \log R = \text{Log10}(R/R_{Baseline}) + 0.02 * (\Delta t - \Delta t_{Baseline})$

EQUATION 2: $\Delta \log R = \text{Log10}(R/R_{Baseline}) + 4 * (NPHI - NPHI_{Baseline})$

EQUATION 3: $\Delta \log R = \text{Log10}(R/R_{Baseline}) - 2.5 * (RHOB - RHOB_{Baseline})$

EQUATION 4: $TOC = (\Delta \log R) * 10^{(2.297 - 0.1688 * LOM)}$

sistivity log curve data are shown on Figure 1.

When utilizing the Passey method, a term Δ log R is calculated that represents the separation between the deep resistivity curve and the available porosity log curve (i.e. sonic, density or neutron log). This calculation can be done for each of the porosity log types (Table 1, equations 1-3).

Next, for wells with TOC sample data, an equation is solved to determine level of organic maturity (LOM) (Table 1, equation 4).

Figure 2 shows the close agreement between a calculated TOC curve and TOC sample data points for the Marcellus Shale interval.

Perform Petrophysical Analysis

As noted above, the Passey approach is used to calculate LOM for each of the 65 wells within the trend that have Marcellus interval TOC sample data. The LOM calculated values then can be contoured. Each of the wells within the trend that have porosity and resistivity log data for the Marcellus Shale interval will fall between or on an LOM contour line.

The LOM contour line values then are applied to the equation for a well without TOC data, and the equation is solved for TOC at each logged sample point (wells commonly are logged on a 0.5-foot sample depth interval). A TOC curve is drawn through the calculated TOC sample points for the Marcellus interval in the well using petrophysical software. Also, statistical information, such as the average or maximum TOC over the upper, lower or total Marcellus interval, is calculated.

Once the TOC curve is calculated, a porosity curve can be created (since TOC concentration must be taken into account when calculating porosity in gas shale intervals). Porosity curves can be calculated for wells with sonic, density or neutron porosity log curve data.

Besides TOC and porosity calculations, a few additional petrophysical steps are taken during the analysis. First and foremost, the curves for a well are merged and put on depth, since there may be two or more logging runs that need to be compiled. Suspect log data are flagged. Such data can result from a myriad of problems, typically from washed-out bore hole intervals that result from drilling or from logging tools that get out of calibration. Basic environmental corrections are applied to the data where necessary. Lithology is calculated for the entire logged interval.

Also, potential pyritic zones are flagged by using the response from the photoelectric log if a Pe log is available. Pyritic zones are relatively common in the Marcellus Shale interval, and adversely impact the results of the TOC and porosity calculations. Because there are several thousand wells with Pe log curve data and pyrite impact on the calculation of TOC is so important, pyritic zones are being mapped. These will be noted, since they can mask the presence of sweet spots. The processing steps to flag suspect log data and pyritic zones, and to perform environmental corrections are done for each well analyzed prior to calculating TOC and porosity curves.

In addition, available shear sonic data can be used to evaluate brittleness of the shale, and spectral gamma ray log data can be used to carry out a more detailed lithologic analysis. The Marcellus Shale commonly contains vertical joints or fractures and is known to be brittle, so it should fracture readily during completion.

Some emphasis has been placed on completing more detailed lithologic analysis to identify the more permeable silty zones in gas shales. Fundamentally, shale is composed of silt and clay-sized sediments. The coarser silt-sized material typically results in more effective matrix permeability. The more permeable silty zones have been noted to be more attractive target intervals for implementing fracturing jobs when completing a well. More recent logging tools have been designed to more accurately determine the silt- and clay-sized shale fractions. X-ray diffraction analysis and CT scanning of bore hole cores and/or cuttings also can be used to assess shale sediment size distribution.

There is also conjecture that making the distinction may not be a critical concern for three reasons:

- While drilling laterals to complete a well, new logging tools are designed to identify the more permeable silty zones, and the results are used to keep the drill bit situated within these zones.
- The fracturing jobs impact a relatively large area around the laterals and should effectively reach the more silty permeable zones.
- The core analysis results from recently cored wells indicate that the higher porosity zones tend to coincide with the more permeable zones.

A more rigorous approach can be taken for mapping geologically distinct zones within the upper and lower Marcellus Shale members. Detailed depositional environment and facies maps can be generated while evaluating the wells and mapping the sweet spots. Lithologic zones of interest that are discernable from log analysis and are contained within the gross depositional environment and facies maps can be mapped within the context of a sequence stratigraphic framework.

Map The Results

The next step is to map the geologic (gas shale area and thickness) and petrophysical (TOC and porosity) results. Structural and isopach maps of the Marcellus Shale, the upper and lower members of the Marcellus Shale, and the overlying formations, including the Genesee and Rhinestreet shales, have been generated based on the initial 3,150 wells that have been interpreted. The maps will be revised as the additional wells with Marcellus interval log data within the Marcellus trend are interpreted.

In addition, TOC and porosity results have been mapped for a handful of wells, and again, the maps will be revised after additional wells with resistivity and porosity log data are processed and evaluated. Also, the data associated with the flagged pyritic zones will be evaluated, and these zones will be mapped if the data permits. Next, interpreting and mapping the gross depositional environments and facies associations within a sequence-constrained stratigraphic framework can be completed.

The final step of this process will be

to evaluate production data with respect to the geologic and petrophysical mapped data. Production data for the Marcellus trend are now available, and regulatory changes in Pennsylvania will make Marcellus gas production data accessible in a shorter time following successful well completions. This step will be used to confirm and/or refine the Marcellus gas shale evaluation approach detailed here.

Log data are available for 2 million U.S. oil and gas wells. More than 500,000 of these wells have been digitized, and by year end, the number of digitized wells will exceed 750,000. Production data are available for the entire United States. Geoscience evaluation already has commenced for a number of active trends, such as the Eagle Ford, Bakken and Niobrara formations. ❐

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