Computed Tomography of the Tuscarora Sandstone from the Preston 119 Well

17 April 2018
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Cover Illustration: Example core photo of the Tuscarora Sandstone.


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https://edx.netl.doe.gov/ucr

The data in this report can be accessed from NETL's Energy Data eXchange (EDX) online system (https://edx.netl.doe.gov) using the following link:
https://edx.netl.doe.gov/dataset/preston-119-well
Computed Tomography of the Tuscarora Sandstone from the Preston 119 Well

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17 April 2018

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## Acronyms, Abbreviations, and Symbols

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<tr>
<td>2D</td>
<td>Two-dimensional</td>
</tr>
<tr>
<td>3D</td>
<td>Three-dimensional</td>
</tr>
<tr>
<td>CT</td>
<td>Computed tomography</td>
</tr>
<tr>
<td>CTN</td>
<td>Computed tomography number</td>
</tr>
<tr>
<td>EDX</td>
<td>NETL’s Energy Data eXchange</td>
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<tr>
<td>HU</td>
<td>Hounsfield unit</td>
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<tr>
<td>NETL</td>
<td>National Energy Technology Laboratory</td>
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<td>WVGES</td>
<td>West Virginia Geological and Economic Survey</td>
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ABSTRACT
The computed tomography (CT) facilities at the National Energy Technology Laboratory (NETL) Morgantown, West Virginia site were used to characterize core of the Tuscarora Sandstone from a vertical well in Preston County WV, the Preston-119 from a depth of 7,165 to 7,438 ft.

The primary impetus of this work is a collaboration between West Virginia Geological and Economic Survey (WVGES) and NETL to characterize core from multiple wells to better understand the geologic framework of key stratigraphic units in West Virginia. As part of this effort, bulk scans of core were obtained from the Pres-119 well, provided by the WVGES. This report, and the associated scans generated, provide detailed datasets not typically available for researchers to analyze. The resultant datasets are presented in this report, and can be accessed from NETL's Energy Data eXchange (EDX) online system using the following link: https://edx.netl.doe.gov/dataset/preston-119-well.

All equipment and techniques used were non-destructive, enabling future examinations to be performed on these cores with the background information gathered through these tests. None of the equipment used was suitable for direct visualization of the pore space, though fractures and discontinuities were detectable with the methods tested. Low resolution CT imagery with the NETL medical CT scanner was performed on the entire core. Qualitative analysis of the medical CT images, give the ability to quickly identify key areas for more detailed study with higher resolution and will save time and resources in future studies. These methods provided a multi-scale analysis of this core that is relevant for many subsurface energy related examinations that have traditionally been performed at NETL.
1. **INTRODUCTION**

This is a collaboration between West Virginia Geological and Economic Survey (WVGES) and National Energy Technology Laboratory (NETL) to characterize core from multiple wells to better understand the geologic framework of various formations in, West Virginia. As part of this effort, we have obtained bulk scans of core archived by the WVGES; including Pres-119 in Preston County, West Virginia.

The primary objective of this report is to provide core characterization with methods not available to most researchers after obtaining baseline information on sample condition and characteristics using fast computed tomography (CT) scanning techniques on large batches of samples. The data is presented in several formats here and online that are potentially useful for various analyses; however, little detailed analysis is presented herein, as the research objective was not to do a site characterization. The data has been collected and preserved for others to utilize.

The Pres-119 well, located at geographic coordinates, 39.238527, -79.571704, was drilled by the Cities Service Oil Company from 10/5/1963 to 3/17/1964, with cored depths of 7,165 to 7,438 ft. The gas well, with a total vertical depth of 9,910 ft (ground elevation 2,172 ft) was drilled to the Martinsburg Formation and plugged in 1985; the API# is 4707700119. The cored interval contains fine-grained sandstone of the Silurian age Tuscarora Sandstone and contains multiple features of interest. The core is 6 in. in diameter contained in 107 boxes.

![Image of map showing the location of Pres-119 well](image)

*Figure 1: Location map for the Preston 119 Tuscarora well.*
2. **CORE DESCRIPTION**

The core ranges from fine to coarse grained quartz rich sandstone (orthoquartzite or quartz arenite) tightly cemented with silica interbedded with argillaceous siliceous sandstone. Beds range from thin to thick. Some thin (6 in) layers of black shale and conglomerates alternate with the cemented sandstone. Coarse quartz grains and pebbles are found occasionally. Faint cross bedding is present throughout as well as filled and unfilled fractures. A detailed log of the core along with thin section descriptions and additional physical property measurements can be found online at [http://www.wvgs.wvnet.edu/pipe2/EfileViewer.aspx](http://www.wvgs.wvnet.edu/pipe2/EfileViewer.aspx) (West Virginia Geological & Economic Survey, 2018)

2.1 **CORE PHOTOGRAPHS**

The following figures are photographs of the Preston 119 core as received at NETL.
Figure 2: Pres-119 core photographs, from 7,165 to 7,171 ft.
Figure 3: Pres-119 core photographs, from 7,171 to 7,177 ft.
Figure 4: Pres-119 core photographs, from 7,177 to 7,182 ft.
Figure 5: Pres-119 core photographs, from 7,183 to 7,189 ft.
Figure 6: Pres-119 core photographs, from 7,189 to 7,195 ft.
Figure 7: Pres-119 core photographs, from 7,195 to 7,201 ft.
Figure 8: Pres-119 core photographs, from 7,201 to 7,207 ft.
Figure 9: Pres-119 core photographs, from 7,207 to 7,213 ft.
Figure 10: Pres-119 core photographs, from 7,213 to 7,219 ft.
Figure 11: Pres-119 core photographs, from 7,219 to 7,225 ft.
Figure 12: Pres-119 core photographs, from 7,225 to 7,231 ft.
Figure 13: Pres-119 core photographs, from 7,231 to 7,237 ft.
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Figure 20: Pres-119 core photographs, from 7,273 to 7,279 ft.
Figure 21: Pres-119 core photographs, from 7,279 to 7,285 ft.
Figure 22: Pres-119 core photographs, from 7,286 to 7,291 ft.
Figure 23: Pres-119 core photographs, from 7,291 to 7,297 ft.
Figure 24: Pres-119 core photographs, from 7,297 to 7,302 ft.
Figure 25: Pres-119 core photographs, from 7,303 to 7,309 ft.
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Figure 26: Pres-119 core photographs, from 7,310 to 7,315 ft.
Figure 27: Pres-119 core photographs, from 7,315 to 7,321 ft.
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Figure 45: Pres-119 core photographs, from 7,422 to 7,428 ft.
Figure 46: Pres-119 core photographs, from 7,428 to 7,434 ft.
Figure 47: Pres-119 core photographs, from 7,434 to 7,438 ft.
3. DATA ACQUISITION AND METHODOLOGY

The core was evaluated using CT scanning and traditional core logging. CT scans and core logging were performed on the 2/3 slabbed cores shown in the previous photographs to maximize the internal area of the core that could be visualized.

3.1 MEDICAL CT SCANNING

Core scale CT scanning was done with a medical Toshiba® Aquilion TSX-101A/R medical Scanner as shown in Figure 48. The medical CT scanner generates images with a resolution in the millimeter range, with scans having voxel resolutions of 0.43 x 0.43 mm in the XY plane and 0.50 mm along the core axis. The scans were conducted at a voltage of 135 kV and at 200 mA. Subsequent processing and combining of stacks was performed to create three-dimensional (3D) volumetric representations of the cores and a two-dimensional (2D) cross-section through the middle of the core samples using ImageJ (Rasband, 2018). The variation in greyscale values observed in the CT images indicates changes in the CT number obtained from the CT scans, which is directly proportional to changes in the attenuation and density of the scanned rock. Darker regions are less dense. While the medical CT scanner was not used for detailed characterization in this study, it allowed for non-destructive bulk characterization of the core, and thus complimented the MSCL data on the resultant logs.

![Figure 48: Toshiba® Aquilion™ Multislice Helical Computed Tomography Scanner at the NETL used for core analysis.](image)

3.2 DUAL ENERGY SCANS

This data can be accessed from NETL's Energy Data eXchange (EDX) online system using the following link: https://edx.netl.doe.gov/dataset/preston-119-well.
4. **RESULTS**

Processed 2D slices of the medical CT scans through the cores are shown first, followed by the dual energy scans.

4.1 **MEDICAL CT SCANS**

As previously discussed, the variation in greyscale values observed in the medical CT images indicates changes in the CT number obtained, which is directly proportional to changes in the attenuation and density of the scanned rock (i.e. darker regions are less dense).

Core was scanned in 3 ft or smaller sections due to the limitation of how many images could be generated for each scan. In highly-fractured core, sections in excess of 3 ft were often scanned. Detailed information in log books and photographs of cores were used to merge multiple scans of cores when this occurred. In the following images, the reported depth (top and bottom) for each scanned sub-section of core is listed.
Figure 49: 2D isolated planes through the vertical center of the medical CT scans of the Pres-119 core from 7,165 to 7,180 ft.
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Figure 55: 2D isolated planes through the vertical center of the medical CT scans of the Pres-119 core from 7,244 to 7,259 ft.
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Figure 62: 2D isolated planes through the vertical center of the medical CT scans of the Pres-119 core from 7,344.5 to 7,356.5 ft.
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Figure 66: 2D isolated planes through the vertical center of the medical CT scans of the Pres-119 core from 7,393 to 7,406 ft.
Figure 67: 2D isolated planes through the vertical center of the medical CT scans of the Pres-119 core from 7,406 to 7,417 ft.
Figure 68: 2D isolated planes through the vertical center of the medical CT scans of the Pres-119 core from 7,417 to 7,429 ft.
Figure 69: 2D isolated planes through the vertical center of the medical CT scans of the Pres-119 core from 7,429 to 7,438 ft.
4.2 ADDITIONAL CT DATA

Additional CT data can be accessed from NETL's EDX online system using the following link: https://edx.netl.doe.gov/dataset/preston-119-well. The original CT data is available as 16-bit tif stacks suitable for reading with ImageJ (Rasband, 2018) or other image analysis software. In addition, videos showing the variation along the length of the cross-section images shown in the previous section are available for download and viewing. A single image from these videos is shown in Figure 70, where the distribution of high density minerals in a cross section of the core around a depth of 7,372 ft is shown. Here, the red line through the XZ-plane image of the core shows the location of the XY-plane displayed above. The videos on https://edx.netl.doe.gov/dataset/preston-119-well show this XY variation along the entire length of the core.

Figure 70: Single image from a video file available on EDX showing variation in the core around 7,372 ft. Image above shows the variation in composition within the matrix perpendicular to the core length.

4.3 DUAL ENERGY

Dual Energy CT scanning uses two sets of images, produced from different x-ray energies, to approximate the density ($\rho_B$) and the effective atomic number ($Z_{eff}$) (Siddiqui and Khamees, 2004; Johnson, 2012). The technique relies on the use of several standards of known $\rho_B$ and $Z_{eff}$ to be scanned at the same energies as the specimen. These scans are performed at lower energies (<100 KeV) and higher energies (>100 KeV) to induce two types of photon interactions with the object (Figure 71). The lower energy scans induce photoelectric absorption, which occurs when the energy of the photon is completely absorbed by the object mass and causes ejection of an outer orbital electron (Figure 71a). The high energy scans induce Compton scattering, which causes a secondary emission of a lower energy photon due to incomplete absorption of the photon energy in addition to an electron ejection (Figure 71b).
Medical grade CT scanners are typically calibrated to known standards, with the output being translated in CT numbers (CTN) or Hounsfield Units (HU). Convention for HU defines air as -1000 and water as 0. A linear transform of recorded HU values is performed to convert them into CTN. This study used CTN as it is the native export format for the instrument, but it is possible to use HU. Dual energy CT requires at least 3 calibration points and it is prudent to utilize standards that approximate the object or material of interest. Pure samples of aluminum, graphite, and sodium chloride were used as the calibration standards as they most closely approximate the rocks and minerals of interest (Table 1). Most materials denser than water or with higher atomic masses have a non-linear response to differing CT energies (Table 2).

### Table 1: Calibration standards

<table>
<thead>
<tr>
<th>Material</th>
<th>( \rho_s ) (g/cm(^3))</th>
<th>( Z_{\text{eff}} )</th>
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<tbody>
<tr>
<td>Air</td>
<td>0.001</td>
<td>7.22</td>
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<tr>
<td>Water</td>
<td>1</td>
<td>7.52</td>
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<tr>
<td>Graphite</td>
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<td>6</td>
</tr>
<tr>
<td>Sodium Chloride</td>
<td>2.16</td>
<td>15.33</td>
</tr>
<tr>
<td>Aluminum</td>
<td>2.7</td>
<td>13</td>
</tr>
</tbody>
</table>
Table 2: Response to differing CT energies

<table>
<thead>
<tr>
<th>Material</th>
<th>HU</th>
<th>CTN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>80 KeV</td>
<td>135 KeV</td>
</tr>
<tr>
<td>Air</td>
<td>-993</td>
<td>-994</td>
</tr>
<tr>
<td>Water</td>
<td>-3.56</td>
<td>-2.09</td>
</tr>
<tr>
<td>Graphite</td>
<td>381</td>
<td>437</td>
</tr>
<tr>
<td>Sodium Chloride</td>
<td>1,846</td>
<td>1,237</td>
</tr>
<tr>
<td>Aluminum</td>
<td>2,683</td>
<td>2,025</td>
</tr>
</tbody>
</table>

Dual energy CT utilizes these differences to calibrate to the X-ray spectra. Two equations with 3 unknowns each are utilized to find $\rho_B$ and $Z_{\text{eff}}$:

$$\rho_B = m\text{CTN}_{\text{low}} + p\text{CTN}_{\text{high}} + q$$

$$Z_{\text{eff}} = \frac{3.6 \sqrt{(r\text{CTN}_{\text{low}} + s\text{CTN}_{\text{high}} + t)}}{(0.9342 + \rho_B + 0.1759)}$$

Where $[m, p, and q]$ and $[r, s, and t]$ are unknown coefficients that can be solved by setting up a system of equations with four $3 \times 3$ determinants. The CTN is obtained from the CT scans for each of the homogenous calibration standards.

In this study the high and low energy image stacks were loaded into Python as arrays. A 3-D Gaussian blur filter with a sigma of 2 was used to reduce noise in the images. The scipy.solv module of Python was then employed to solve for the coefficients based on the calibration CTN values. The $\rho_B$ and $Z_{\text{eff}}$ were both solved for each pixel in the 3D volume and saved as two new separate image stacks.

ImageJ (Rasband, 2018) was used to reslice the image stacks to produce 2D representative cross-sections of the entire core-length. A 6-shade look up table was used to apply a gradational color scale to the image with the total range of values limited to densities from 2 to 4.5 $\text{g/cm}^3$; this eliminated much of the noise in the air portion of the scans and at the edges of the sample. The average density along the length of the cores was calculated by excluding all densities below 2 $\text{g/cm}^3$. This study assumed that the cores were free of water and liquids as they were air dried and that the cores do not contain an appreciable quantity of elements with densities lower than 2.0 $\text{g/cm}^3$. 
Computed Tomography of the Tuscarora Sandstone from the Preston 119 Well

Figure 72: Dual-energy density, CT images, and core description for the Pres-119 core from 7,165 to 7,236 ft.

Silica cemented quartz rich orthoquartzite sandstone, light grey in color, fine to medium grained with a few coarse clasts; occasionally faintly cross-bedded, fractured (open and healed), vugs.

Same as above with lenses of dark grey loosely cemented sandstone, some beds are graded, conglomeratic lenses present, horizontally laminated

Coarse conglomeratic orthoquartzite interbedded with loosely cemented and tightly cemented orthoquartzite, clay content increases with depth

Black shale present, ~ 6 inches thick

Interbedded tightly cemented and loosely cemented orthoquartzite with siltstones or conglomeratic sandstone, some cross-beds present

Well: Pres 119
Starting elevation 2172.12'
Lat: 39.238527 N
Long: 79.571704 W
Preston County, WV

Measurements performed at the US Department of Energy
National Energy Technology Laboratory
Morgantown, WV
January 2018

Analysis By: Johnathan Moore, Dustin Crandall & Sarah Brown
Data Collection: Scott Workman
Figure 73: Dual-energy density, CT images, and core description for the Pres-119 core from 7,236 to 7,307 ft.
Figure 74: Dual-energy density, CT images, and core description for the Pres-119 core from 7,307 to 7,372 ft.
Figure 75: Dual-energy density, CT images, and core description for the Pres-119 core from 7,372 to 7,438 ft.
5. **DISCUSSION**

CT analysis provides a unique look into the internal structure of the core and macroscopic changes in lithology. The multiple CT techniques used here:

- Are non-destructive
- Provide density values over the core length
- Can be used to identify zones of interest for detailed analysis, experimentation, and quantification
- Provide a detailed digital record of the core, before any destructive testing or further degradation, that is accessible and can be referenced for future studies
6. REFERENCES


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