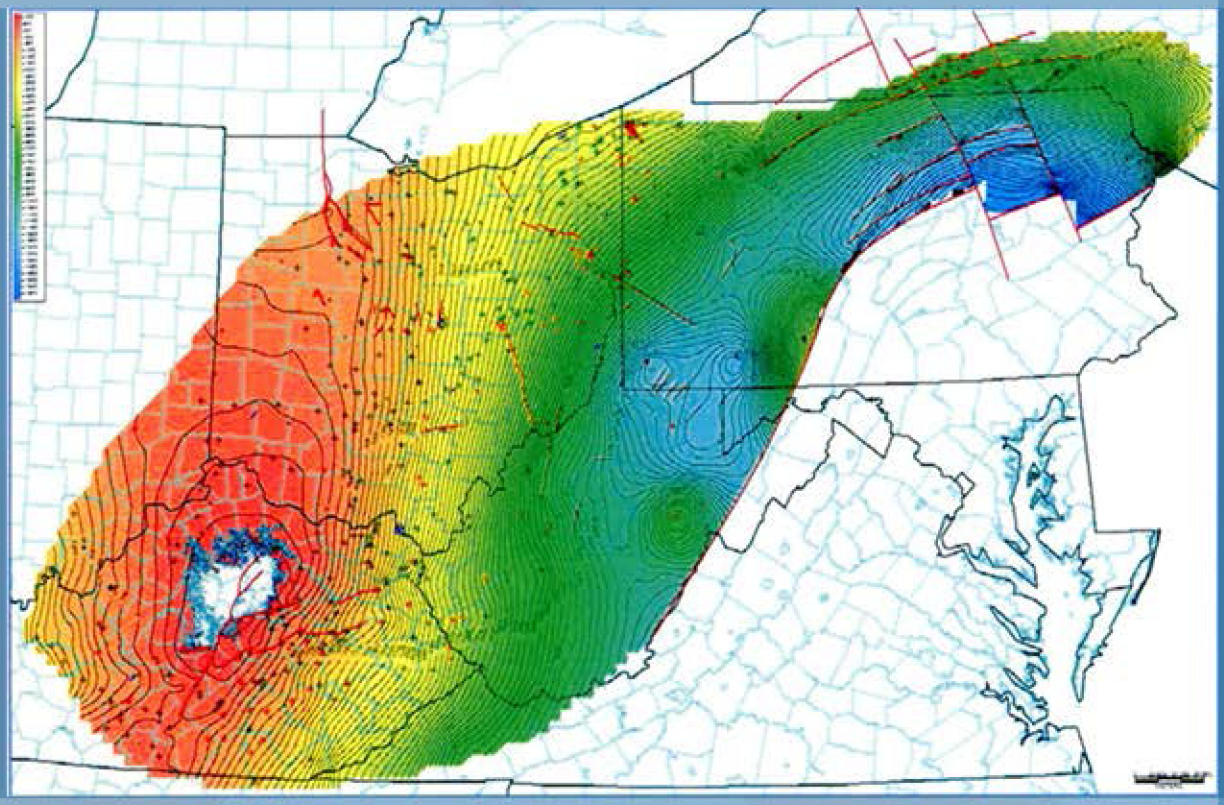
# A Geologic Play Book for Utica Shale Appalachian Basin Exploration



**FINAL REPORT**
**April 1, 2012**
**July 1, 2015**

(Sections)

## 1.0 INTRODUCTION AND PURPOSE

**Utica Shale Appalachian Basin Exploration Consortium**
Coordinated by the Appalachian Oil & Natural Gas Consortium at West Virginia University

# A GEOLOGIC PLAY BOOK FOR UTICA SHALE APPALACHIAN BASIN EXPLORATION

## 1.0 INTRODUCTION AND PURPOSE

This "Geologic Play Book for Utica Shale Appalachian Basin Exploration" (hereafter referred to as the "Utica Shale Play Book Study" or simply "Study") represents the results of a two-year research effort by workers in five different states with the financial support of fifteen oil and gas industry partners. The Study was made possible through a coordinated effort between the Appalachian Basin Oil & Natural Gas Research Consortium (AONGRC) and the West Virginia University Shale Research, Education, Policy and Economic Development Center.

The Utica Shale Play Book Study was designed to: (1) characterize and assess the lithology, source rock geochemistry, stratigraphy, depositional environment(s) and reservoir characteristics of Utica and equivalent rocks in the northern Appalachian basin; (2) define Utica oil and gas fairways by integrating regional mapping work with drilling activity and production tracking efforts; and (3) provide probabilistic and volumetric Utica resource assessments informed by geologic and geochemical data collected during the course of this Study.

## 1.1 Research Team

The Utica Shale Play Book Study research team included AONGRC personnel from the Kentucky Geological Survey (KGS; John Hickman and Cortland Eble); the Ohio Division of Geological Survey (ODGS; Ronald Riley, Matthew Erenpreiss and Mohammad Fakhari); the Pennsylvania Geological Survey (PAGS; Kristin Carter, John Harper and Brian Dunst); the West Virginia Geological and Economic Survey (WVGES; Jessica Moore, Michael Hohn, Susan Pool and John Saucer); Smith Stratigraphic LLC (Langhorne "Taury" Smith and Michele Cooney); Washington University in St. Louis (Garrecht Metzger and David Fike); and the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) (Daniel Soeder and Thomas Mroz). John Barnes of PAGS analyzed hundreds of bulk mineralogy samples for the Study, and James Leone of the New York State Museum (NYSM) performed hundreds of Total Organic Carbon analyses (in collaboration with Smith Stratigraphic LLC). John Repetski of the U.S Geological Survey (USGS) contributed important analyses regarding thermal maturity trends in Upper Ordovician rocks based on conodont alteration indices, and Juergen Schieber of Indiana University performed scanning electron microscopy imaging for selected samples (in collaboration with Smith Stratigraphic LLC). Project management was provided by Douglas Patchen of AONGRC.

## 1.2 Scope of Work

The scope of work for the Utica Shale Play Book Study was divided into nine separate tasks, each of which was assigned a team lead in order to streamline project management efforts. To the extent possible, sampling, data collection and related efforts for each task were conducted by the researchers in each state, and then shared with the team leads for compilation and further

interpretation. In those instances where a task was particularly broad and/or data-intensive, the team lead received support from one or more additional research team members. These nine tasks are shown in Table 1-1.

***Table 1-1. Research efforts by task.***

| Task | Team Lead | Supporting Team Members |
|---|---|---|
| 1.0 Organization of Existing Data | West Virginia Geological and Economic Survey (WVGES) | --- |
| 2.0 Core and Outcrop Descriptions, Petrography, Spectral Gamma-Ray Logging | Ohio Division of Geological Survey (ODGS) | Smith Stratigraphic LLC |
| 3.0 Reservoir Characterization | Pennsylvania Geological Survey (PAGS) | Smith Stratigraphic LLC, U.S. DOE NETL |
| 4.0 Inorganic Geochemistry | Smith Stratigraphic LLC | PAGS, Washington University in St. Louis |
| 5.0 Organic Geochemistry and Petrology | Kentucky Geological Survey (KGS) | USGS, Smith Stratigraphic LLC |
| 6.0 Log Analysis, Stratigraphic Correlation, and Fairway Mapping | KGS | --- |
| 7.0 Resource Assessment | WVGES | KGS |
| 8.0 Data, GIS, and Website Management | WVGES | --- |
| 9.0 Play Book Compilation and Project Management | Douglas Patchen (AONGRC) | --- |

While previous Study progress reports were organized relative to these task headings, this final report has been structured differently to provide for more logical development of our research findings. Specifically, the remainder of this introductory chapter provides the details regarding access, organization and management of all data deliverables for the Utica Shale Play Book Study. Chapter 2 provides the results of Utica drilling activity and production tracking efforts. Chapter 3 describes the lithostratigraphy for Utica and equivalent rocks throughout the Study area. Chapter 4 presents the research team's log analysis, correlation and mapping results. Chapter 5 presents the results of the research team's core studies, including interpretations of depositional environments. Chapter 6 includes the results of the team's inorganic geochemistry research efforts, and Chapter 7 presents Utica source rock geochemistry findings and interpretations. Reservoir pore imaging and porosity/permeability data are provided in Chapter 8. Chapter 9 provides the research team's resource assessment results, and Chapter 10 offers the research team's overarching conclusions and implications for development of the Utica play in the northern Appalachian basin, based on data derived from this Study. A comprehensive list of references is included in Chapter 11, and the report appendices are included at the very end of this document.

## 1.3 Data Deliverables Access, Organization and Management

Data deliverables for the Utica Shale Play Book Study include not only the text, tables, figures and appendices of this final report but also the raw datasets, analyses, and results utilized by the Research Team members. All study-specific data, whether compiled from legacy sources or derived specifically for this work, have been organized and assimilated into a Geographic Information System (GIS) database and interactive mapping application, as well as a searchable Oracle database that is available via the project website. These data may be accessed using the following links/web addresses:

**Project Website and Interactive Map:**
**http://www.wvgs.wvnet.edu/Utica**

**Appalachian Oil and Natural Gas Research Consortium Website (links to Utica site):**
**http://aongrc.nrcce.wvu.edu**

### 1.3.1 Interactive Map Application

The Utica Shale Play Book Study's interactive map application utilizes ESRI ArcGIS Server technology and is designed to allow users to visualize geologic data in spatial context (Figure 1-1). Data include the following:

- Wells
  - With Supplemental Data[1]:
    - Digitized Well Logs
    - Scanned Well Logs
    - Source Rock Analyses
    - Total Organic Carbon (TOC) Data
    - Core Photographs
    - Scanning Electron Microscopy (SEM) Images-Data
    - Thin Section Images
    - Thin Section Descriptions
    - All Wells with Data (i.e. a file on the FTP server)
  - With Formation Tops[2]:
    - Upper Ordovician
    - Kope
    - Utica
    - Point Pleasant
    - Lexington/Trenton (includes Logana and Curdsville members)
    - Black River
- Cross-Sections[3]
  - Lines
  - Wells
- Maps[1]
  - Faults

    - Kope
    - Utica
    - Point Pleasant
    - Lexington/Trenton (includes Logana and Curdsville members)
    - Black River
- Play Areas
    - Utica
    - Ordovician Outcrops

[1] *Data obtained from Utica Shale Project FTP server.*
[2] *Data obtained from Utica Shale Project Petra® file.*
[3] *Data obtained from Trenton-Black River Project.*

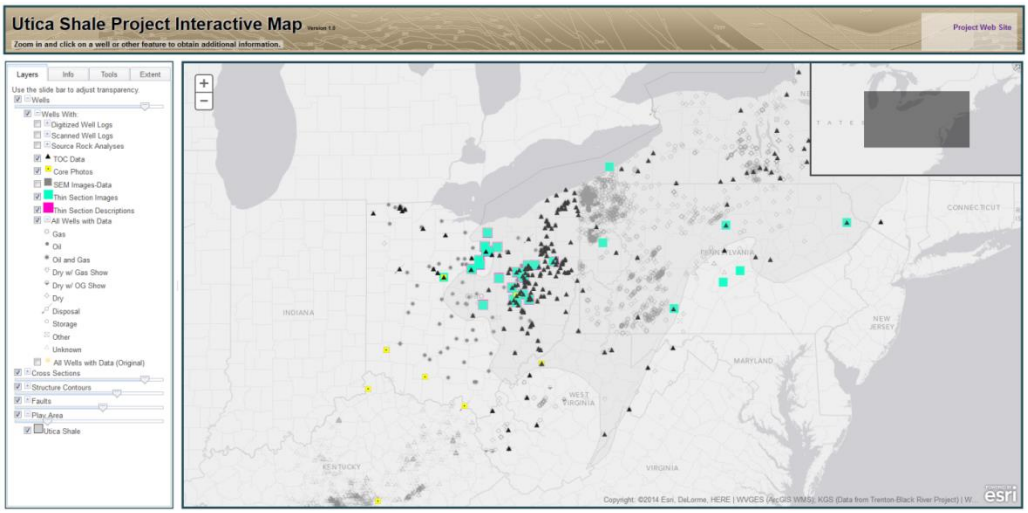



**Figure 1-1. Screen-shot display of the Study's secure interactive map application, which was developed using ArcGIS Server. All wells with files or documents are shown along with wells having TOC data, core photos and thin section data.**

Selecting a well or area on the map will result in a "Layer Info" window that allows users to see the different data types available for the selection (Figure 1-2). Each data type contains a secure link or links to the project database where the data may be retrieved. Links to the well file document search system and any relevant files or documents are available for "Wells With Supplemental Data" layers (Figure 1-2). Also, links to cross-section images are available for "Cross-Section Line" layers. The application provides the ability to switch base maps as well as basic navigation and print tools.

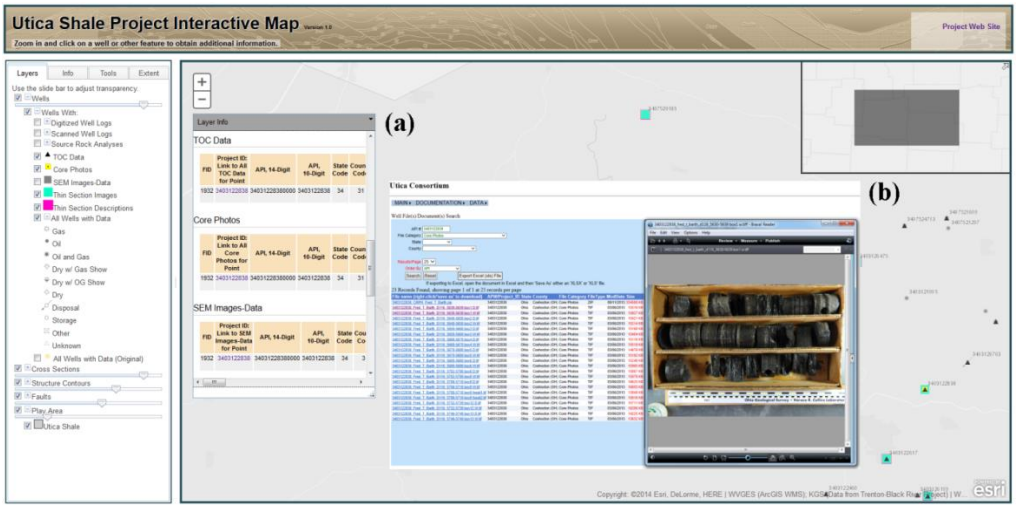



**Figure 1-2. Screen-shot display showing the Study's interactive map application. (a) Popup window with additional information, which is accessed by clicking on a well or other feature in the interactive map. (b) ) Well file document search system window and a core photo. Search system and files or documents (e.g., core photos) are accessed from the map application using links in the popup window.**

### 1.3.2 Play Book Study Website

The Utica Shale Play Book Study website is the main source of data collected and generated for the project. This website runs on a Microsoft Windows server using IIS 7.0 and SSL encryption.

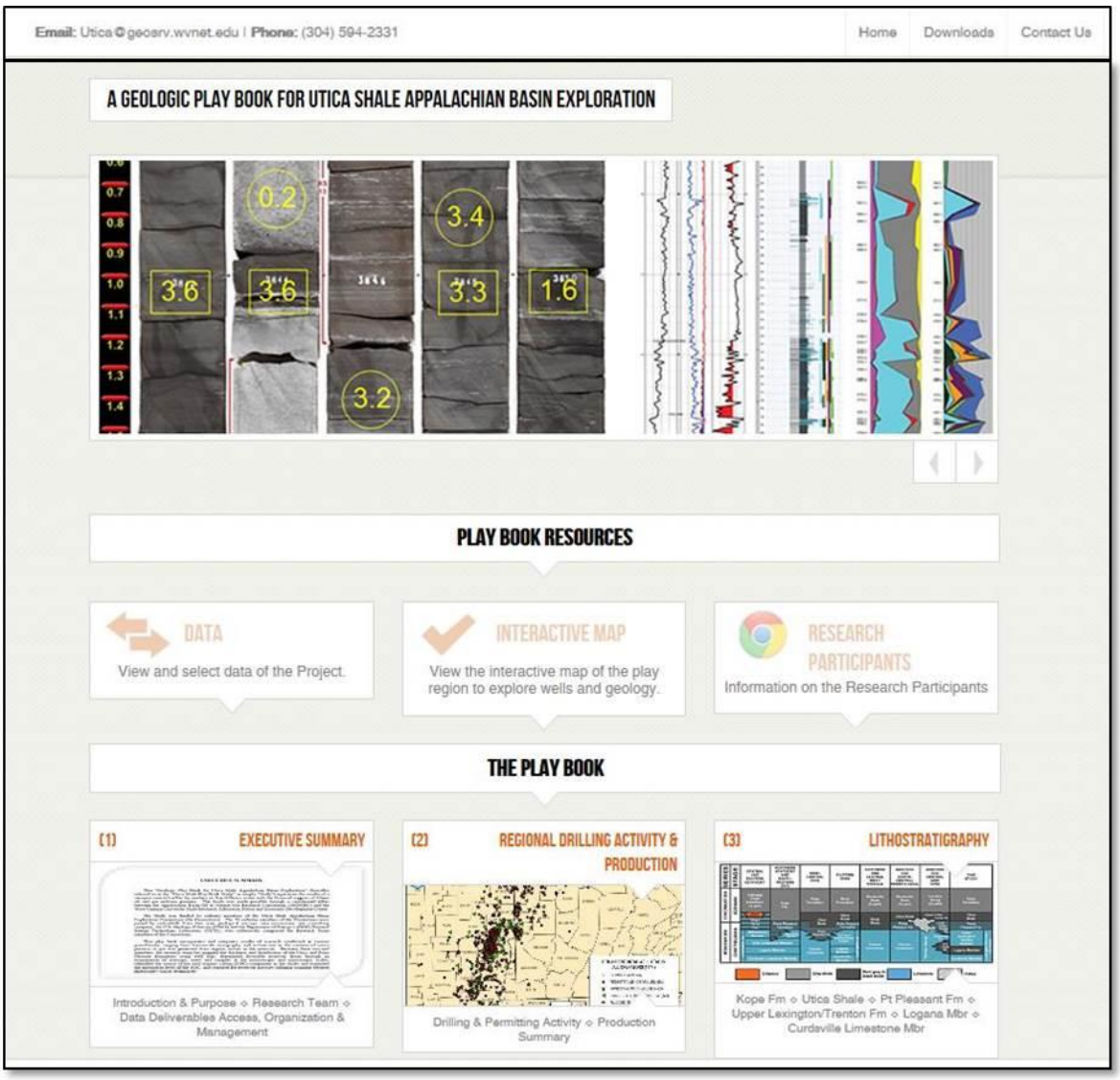



**Figure 1-3. Utica project website homepage.**

The website contains project information and data under three main categories: "Data", "Interactive Map" (See section 1.3.1 for details) and "The Play Book" (Figure 1-3). Each chapter of the final project report is accessed via its own section of "The Play Book". Links to the corresponding appendices are embedded within the text, enabling users to access related data as they read through the body of the chapter.

Figure 8-3 includes selected photomicrographs for each of the samples listed in Table 8-1, and Appendix 8-A (PDF, 3.61 MB) includes the entire suite of photomicrographs for samples analyzed for this work. The scale of these images is on the order of tens of µm, and they illustrate the tight nature of the shale matrix in these samples. At this scale, mineral grains are clearly visible, but true pore space (whether phyllosilicate framework, dissolution or organic matter pores) cannot be resolved. In the case of the Utica outcrop samples (Figure 8-3), pyrite grains plucked from some samples (due to either handling during sample collection or weathering at the outcrop) have left polygonal-shaped voids (pop-out holes).

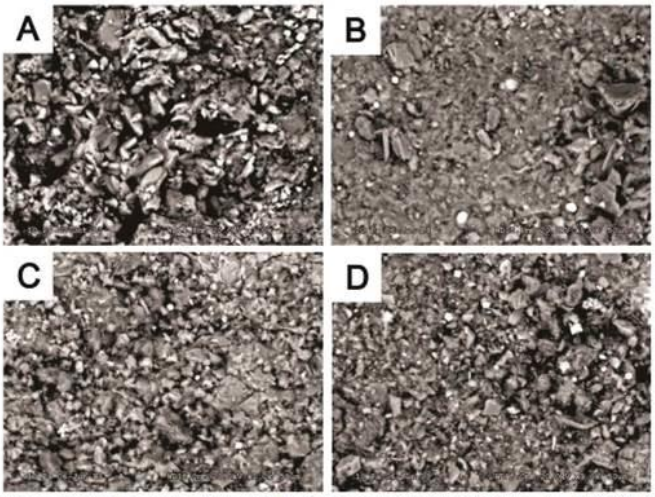



Figure 8-3. Photomicrographs of selected specimens analyzed by PAGS using standard SEM techniques. A - S12-061-003, Utica Shale outcrop, Reedsville exit ramp, Mifflin County, Pennsylvania; B - S13-013-001, top Utica Shale (8504-8513 ft), Hockenberry No. 1 (API#3701990063), Butler County, Pennsylvania; C - S13-014-003, Point Pleasant Formation (3750-3760 ft), Shade Mt. No. 1 (API#3706720001), Juniata County, Pennsylvania; D - S13-015-001, Point Pleasant Formation (13,440-13,450 ft), PA Tr. 163 No. C-1 (API#3710320003), Pike County, Pennsylvania.

| API No. | County | Location/Well Name | Sample Depths (ft) | Formation/ Member | Figure No. |
|---|---|---|---|---|---|
| 3700920034 | Bedford/PA | Schellsburg Unit No. 1 | 7,690 | Lexington/Trenton | 8-4A |
| 3703520276 | Clinton/PA | Commonwealth of PA Tr. 285 No. 1 | 14,480 | Lexington/Trenton | 8-4B |
| 3704920049 | Erie/PA | PA Dept. of Forests & Waters Block 2 No. 1 | 4,096 | Lexington/Trenton | 8-4C |
| 3706720001 | Juniata/PA | Shade Mt. No. 1 | 3,750 | Point Pleasant | 8-4D |
| 3708720002 | Mifflin/PA | Commonwealth of PA Tr. 377 No. 1 | 5,230 | Lexington/Trenton | 8-4E |
| 3710320003 | Pike/PA | Commonwealth of PA Tr. 163 No. C-1 | 13,580 | Lexington/Trenton | 8-4F |
| 3712522278 | Washington/PA | Starvaggi No. 1 | 10,040 | Kope | 8-4G |
| NA | Herkimer/NY | 74NY5 Mineral Core | 170 - 730 | Point Pleasant Logana | 8-5 |

*NA – not applicable*

Table 8-2. Samples analyzed using ion milling and SEM techniques.

**Figure 1-4. Within each chapter of the Utica Play Book, links to corresponding appendices are embedded within the text, allowing users to access the referenced data as they read through the chapter.**

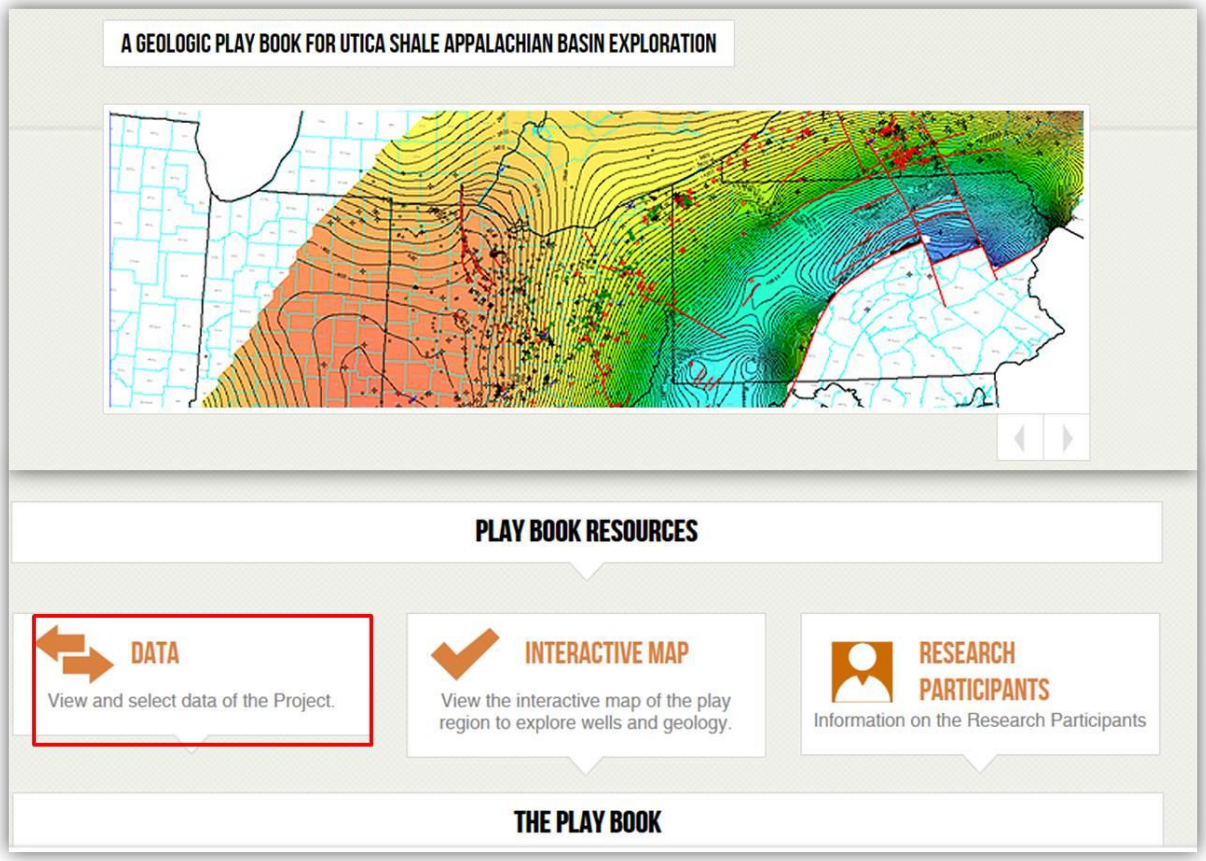



**Figure 1-5. Screen-shot display of the Utica project home page with "Data" tab highlighted (http://www.wvgs.wvnet.edu/Utica).**

The "Data" section of the website contains all data collected, processed and analyzed during the course of the project's research. Website users may access these data via a well document file search, which links to the project database (Figure 1-5). This document search allows users to create a custom search of the project database. A search may utilize one or more of the following criteria:

- API number
- File category (see Table 1-2 for file category types)
- State
- County

Results of the data search may also be exported to Excel, where the data are able to be further sorted (Figure 1-6). Hyperlinks to the individual files are embedded in the Excel file, which allows users to link back to the project webpage to retrieve the data without performing a duplicate search.

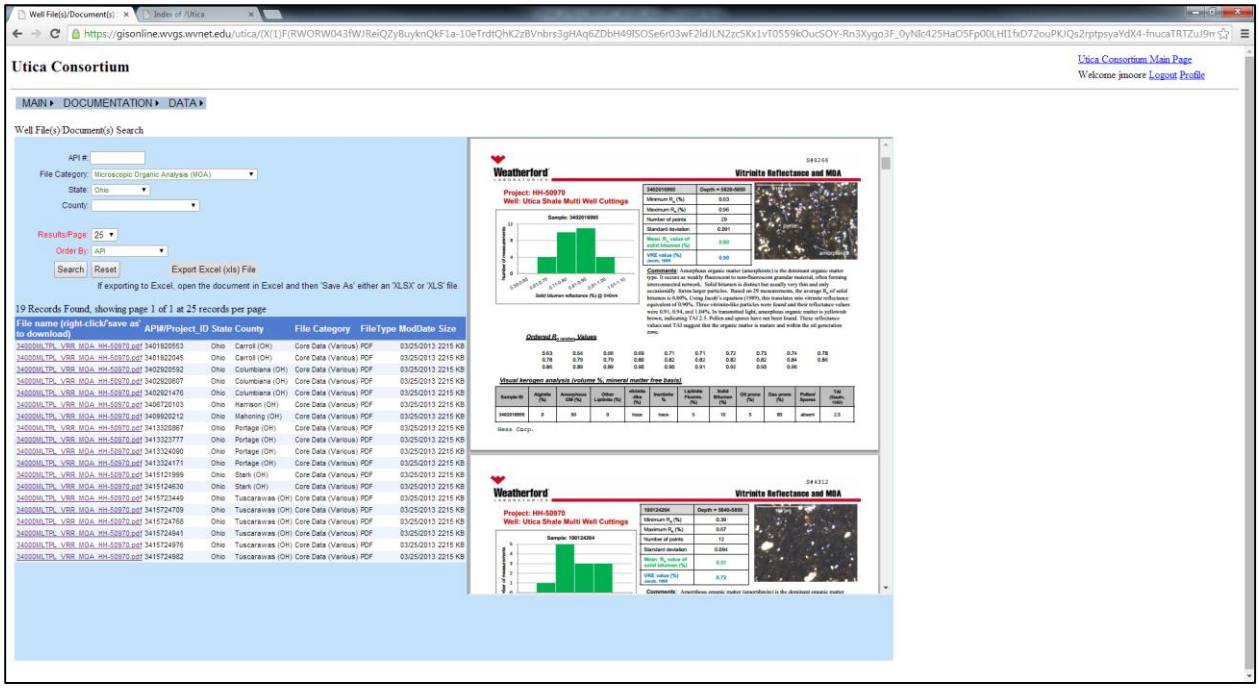



**Figure 1-6. Example of a customized Utica database search (Microscopic Organic Analysis, Ohio) with results. The results may also be exported to an Excel file, which allows further sorting of the data. The Excel file also contains links back to each file, which eliminates the need for duplicate searches across multiple work sessions.**

### 1.3.3 Data Management

The Consortium database utilizes Oracle 11g technology. The database was initially populated with metadata of the documents uploaded by research team members in fulfillment of the requirements of Task 1 (Organization of Existing Data) and has been periodically updated as new data have become available. This searchable database is now available via the project website (http://www.wvgs.wvnet.edu/utica). All data are organized by API number, as available. If an API number was not available, a Project ID was generated for the well or document.

The folder structure within the Consortium database was initially organized so that each well document file would be classified within a single file category (e.g., Digital Logs, Sample Descriptions, etc.). This file category would serve as the root of the directory folder, with subfolders for each state within the root category. As organization of the data progressed, it became apparent that a given document may contain several data types and would need to be cross-listed within the database. Table 1-2 lists the file categories, abbreviations, and document counts for the database (current as of July 9, 2014).

***Table 1-2. Consortium file categories, abbreviations and number of files per state. Data categories and counts are current as of July 9, 2014.***

| FILECATEGORYCODE | FILECATEGORYLONG | | KY | NY | OH | PA | WV | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| BIOSTRAT | Biostratigraphy | | | | 12 | | | | 12 |
| CRPH | Core Photos | | 146 | | 1046 | | 62 | | 1254 |
| CRPHZ | Core Photos Zipped | | | | 5 | | | | 5 |
| CSP | Crushed Stone Properties (CSP) | | | | 1 | | | | 1 |
| CTDAT | CT Scan Data | | | | 11 | | | | 11 |
| CTIMG | CT Image | | | | 220 | | | | 220 |
| CTIMGZ | CT Zipped Images(CTIMGZ) | | | | 9 | | | | 9 |
| DLOG | Digitized Logs | | 2 | 501 | 170 | 112 | 29 | | 814 |
| ELOG | Scanned Logs | | | 1007 | 31 | 164 | 120 | | 1322 |
| FIR | Fluid Inclusion Report | | | | 1 | | | | 1 |
| GEOCHEM | Geo Chem | | | | 2 | | | | 2 |
| ISO | Isotopes | | 2 | | 10 | | | | 12 |
| LOGT | Log Tops | | | | | 2 | | | 2 |
| MICP | High Pressure Mercury Injection Porosity (MICP) | | | | 12 | | | | 12 |
| MNRLGY | General Mineralogy (MNRLGY) | | | | 8 | | | | 8 |
| MOA | Microscopic Organic Analysis (MOA) | | | | 19 | | | | 19 |
| OTHR | Other Well Documents | | | 104 | 27 | 22 | | | 153 |
| RCA | Routine Core Analysis (grain size) (RCA) | | | | 8 | | | | 8 |
| RKMECH | Rock Mechanics | | | | 9 | | | | 9 |
| ROHIST | Ro Histograms | | | | 10 | | | | 10 |
| SEM | Scanning Electron Microscope (SEM) | | | 144 | 348 | 444 | | | 936 |
| SEMZ | SEM Zipped Images (SEMZ) | | | | 5 | 14 | | | 19 |
| SMDS | Sample Descriptions | | | 72 | 19 | 1 | | | 92 |
| SRA | Source Rock Analyses (SRA) | | | 53 | 263 | 12 | 15 | | 343 |
| TOC | Total Organic Carbon (TOC) | | | 53 | 260 | 12 | 15 | | 340 |
| TRA | Tight Rock Analysis (TRA) | | | | 23 | | | | 23 |
| TSDESC | Thin Section Description | | | | 29 | | | | 29 |
| TSIMG | Thin Section Image | | | | 878 | 53 | | | 931 |
| TSIMGZ | Thin Section Zipped Images | | | | 7 | | | | 7 |
| VRR | Vitrinite Reflectance Report | | | | 59 | 17 | | | 76 |
| XRD | X-Ray Defraction (XRD) | | | 10 | 138 | 68 | 13 | | 229 |
| XRF | X-Ray Fluorescence (XRF) | | | | 6 | | | | 6 |

Due to the necessity of cross-listing a single document file under several categories, a naming convention was devised that would support multiple classifications. Each well or document file is first named according to API number (10- or 14-digit). If an API number is unavailable (e.g., outcrop sections, water wells, etc.), the file is given an internal Project ID by the following convention:

# Utica Shale Play Book

**The AONGRC's Utica Shale Appalachian Basin Exploration Consortium includes the following members:**

**Research Team:**
WVU National Research Center for Coal and Energy, Washington University, Kentucky Geological Survey, Ohio Geological Survey, Pennsylvania Geological Survey, West Virginia Geological and Economic Survey, U.S. Geological Survey, Smith Stratigraphic, and U.S. DOE National Energy Technology Laboratory.

**Sponsorship:**
Anadarko, Chevron, CNX, ConocoPhillips, Devon, EnerVest, EOG Resources, EQT, Hess, NETL Strategic Center for Natural Gas and Oil, Range Resources, Seneca Resources, Shell, Southwestern Energy, and Tracker Resources.

**Coordinated by:**
Appalachian Oil & Natural Gas Research Consortium at West Virginia University