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Final Report

Improving the Availability and Delivery of Critical Information for Tight Gas Resource Development in the Appalachian Basin

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ABSTRACT

To encourage, facilitate and accelerate the development of tight gas reservoirs in the Appalachian basin, the geological surveys in Pennsylvania and West Virginia collected widely dispersed data on five gas plays and formatted these data into a large database that can be accessed by individual well or by play. The database and delivery system that were developed can be applied to any of the 30 gas plays that have been defined in the basin, but for this project, data compilation was restricted to the following: the Mississippian-Devonian Berea/Murrysville sandstone play and the Upper Devonian Venango, Bradford and Elk sandstone plays in Pennsylvania and West Virginia; and the "Clinton"/Medina sandstone play in northwestern Pennsylvania. In addition, some data were collected on the Tuscarora Sandstone play in West Virginia, which is the lateral equivalent of the Medina Sandstone in Pennsylvania.

Modern geophysical logs are the most common and cost-effective tools for evaluating reservoirs. Therefore, all of the well logs in the libraries of the two surveys from wells that had penetrated the key plays were scanned, generating nearly 75,000 scanned e-log files from more than 40,000 wells. A standard file-naming convention for scanned logs was developed, which includes the well API number, log curve type(s) scanned, and the availability of log analyses or half-scale logs.

In addition to well logs, other types of documents were scanned, including core data (descriptions, analyses, porosity-permeability cross-plots), figures from relevant chapters of the Atlas of Major Appalachian Gas Plays, selected figures from survey publications, and information from unpublished reports and student theses and dissertations. Monthly and annual production data from 1979 to 2007 for West Virginia wells in these plays are available as well. The final database also includes digitized logs from more than 800 wells, sample descriptions from more than 550 wells, more than 600 digital photos in 1-foot intervals from 11 cores, and approximately 260 references for these plays.

A primary objective of the research was to make data and information available to producers through an on-line data delivery model designed for public access on the Internet. The web-based application that was developed utilizes ESRI's ArcIMS GIS software to deliver both well-based and play-based data that are searchable through user-originated queries, and allows interactive regional geographic and geologic mapping that is play-based. System tools help users develop their customized spatial queries.

A link also has been provided to the West Virginia Geological Survey's *"pipeline"* system for accessing all available well-specific data for more than 140,000 wells in West Virginia. However, only well-specific queries by API number are permitted at this time.

The comprehensive project web site resides on West Virginia Geological Survey's servers and links are provided from the Pennsylvania Geological Survey and Appalachian Oil and Natural Gas Research Consortium web sites.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Appalachian Oil and Natural Gas Research Consortium, a program within the National Research Center for Coal and Energy at West Virginia University, was awarded a contract by the Department of Energy to simplify and accelerate the data collection process for independent producers interested in developing tight gas reservoirs in the Appalachian basin.

Data collection was concentrated on five gas plays of regional significance, as determined by historical and current activity, and remaining gas resources. These five plays are the Mississippian-Devonian Berea/Murrysville sandstone Play and three Upper Devonian sandstone plays (Venango, Bradford and Elk) in Pennsylvania and West Virginia, and the Lower Silurian "Clinton"/Medina Play in Pennsylvania. Additional data were collected for the Tuscarora Sandstone play in West Virginia, which is a lateral equivalent to the Medina in Pennsylvania.

The first objective of this project was to advance the understanding of these tight gas accumulations by collecting and compiling into a comprehensive project database, a broad range of data and information formerly dispersed in public records, file drawers, core facilities, publications, and digital databases created while performing former contractual work. The second objective was to make the information in this new database more readily available through an on-line, interactive geospatial delivery model designed for public access on the internet.

To meet these objectives, three research tasks were designed and implemented. The first of these was to assemble a broad spectrum of relevant data, including well logs, cores and core descriptions, analyses and photos, for wells in the five tight gas reservoirs, and to assemble published and unpublished maps and cross sections of these plays and convert them to a digital format. A second task was to devise an internet-based geospatial data delivery model that would allow easy access to these diverse data by industry and the general public, and the final task was to transfer technology through a cooperative effort with the Petroleum Technology Transfer Council.

The main products of this project are a fully-functional, publicly-available, geospatial database for the five tight gas plays in the two states, and an interactive, web-based GIS application with well-specific and regional data organized by plays.

The final well-specific database includes "header" information on more than 125,000 wells which penetrate the selected plays in the two states, and scanned e-logs for more than 40,000 of those wells. In addition, the database also includes digitized logs for more than 800 wells penetrating these plays; sample descriptions from more than 550 wells; more than 600 digital photos in 1-foot intervals for 11 cores; and approximately 260 references for these plays, including theses, dissertations and numerous unpublished studies. Selected pages, core descriptions, core data, abstracts, conclusions, maps and cross sections were scanned from several of these references, where permitted to do so.

Users can create their own data collection by generating queries through any of several search mechanisms, including: the well header search; the well-based e-log search; the play-based search; or the reference search. Search results can be viewed on-screen, or exported to Microsoft Excel spreadsheets.

The web-accessible, geospatial, interactive mapping system for the six tight gas plays utilizes ESRI's ArcIMS GIS software to display well-specific and play-specific regional data organized by gas play. In addition to well data by play penetration, a basic layer of more than 200,000 oil and gas well locations is provided. The system allows interactive mapping by play that can display geographic and geologic layers, play-specific data and documents, a link to the well-based data search, digitized cross sections, maps of play outlines and fields in the play, maps digitized from the Gas Atlas, other maps digitized for this project, and a link to the scanned documents for each play. System tools are provided to help users develop their customized spatial queries.

The final project web site resides on West Virginia Geological Survey servers; links are provided to the site from the Pennsylvania Geological Survey and Appalachian Oil & Natural Gas Research Consortium web sites. Both surveys plan to maintain the site by providing data updates in the future.

Applications developed for this project are scalable, and can be extended to additional plays in the Appalachian basin, including historic shale plays, such as the Huron, and emerging, frontier plays, such as the Marcellus Shale play, that currently has attracted numerous companies to the Appalachian basin.

REPORT DETAILS

OVERVIEW

Modern geophysical logs are the best and most cost-effective tools for evaluating reservoirs, but ready access to publicly-held logs has not always been possible, especially at the desk of the user. In addition, other important pieces of publicly available information are widely scattered, stored in a variety of places, and usually unknown to producers, or, if known, not readily available. Therefore, to encourage and facilitate the development of tight gas reservoirs in the Appalachian basin, the government sector needed to simplify and accelerate the data collection process and create an effective delivery system to place these data in the hands of independents.

The database format and delivery system that were developed can be applied to any of the 30 gas plays that have been defined in the Appalachian basin. However, for this initial project, data were collected for only five tight gas plays: the Berea/Murrysville sandstone play in Pennsylvania and West Virginia; the Upper Devonian Venango, Bradford and Elk sandstone plays in Pennsylvania and West Virginia; and the "Clinton"/Medina sandstone play in northwestern Pennsylvania. Additionally, data were collected for the Tuscarora Sandstone play in West Virginia because it is a lateral stratigraphic equivalent of the Medina Sandstone is Pennsylvania.

METHODS

The scope of the project was limited not only to the tight sandstone plays listed above, but also to data that could be collected within the offices and libraries of the Pennsylvania and West Virginia geological surveys. Teams were organized within each survey to search their files, map drawers, libraries and warehouses and collect a broad spectrum of relevant data for wells in the plays, and to locate published and unpublished studies on these reservoirs and plays.

This task began with both survey teams identifying all wells that were logged through the five plays of interest. All of these well logs were scanned and further individual well data to be collected were restricted to these wells. These data included cores, core slabs, core photos, core analyses, thin sections made from cores, thin section descriptions and microphotographs. To further enhance the value of the database, a small subset of the well logs was selected to be digitized.

While these relevant data were being collected and organized into a database, another team at the West Virginia Geological Survey was developing an Internet-based geospatial data delivery system that would deliver not only the data described above, but also certain information on stratigraphy, pays, completions, shows and production from the survey's oil and gas database.

RESULTS AND DISCUSSION

Task 1: Research Management Plan

A research management plan for this project was prepared and submitted in October 2005. The report identified the West Virginia University Research Corporation as the prime contractor, but specified that the contract work would be performed by the Appalachian Oil & Natural Gas Research Consortium (AONGRC), an oil- and gas-related research program within the National Research Center for Coal and Energy at West Virginia University. Project management was assigned to the Director of the AONGRC.

The report further defined the research team, consisting of professionals at the Pennsylvania Geological & Topographic Survey (PGTS) and the West Virginia Geological & Economic Survey (WVGES). Two supervisors from each survey joined with the Director of AONGRC to form the complete management team.

The report also documented the work breakdown structure and provided a supporting narrative that included the objectives and approach, work schedule, deliverables and budget for each of the research tasks.

Task2: Technology Status Assessment

A technology status assessment was performed and the results were included in a report submitted in November 2005. The report concluded that although the five plays defined in the work plan have been historically significant in terms of gas production and activity, they also will continue to be important in the future, with remaining resources estimated to range from 20 to 25 trillion cubic feet (Tcf). The report also concluded, that although most gas companies in the Appalachian basin have developed digital databases containing information on their own wells, their presence at geological surveys in search of other data provides testimony as to the need to gather and deliver this information, especially widely scattered, hard to find data, to Appalachian producers at their desktop.

Data to be collected, organized and delivered were to include both individual well and play-based summaries, often in the form of a graphical illustration. Thus, a major problem facing the research team, once the data were actually located, was the amount of time that would be required to organize these widely diversified data in one database and deliver the information to industry. However, it was recognized by the authors of the report, that the successful completion of this project would result in a very important database that could be accessed with relative ease in the office, thereby eliminating costly and time-consuming trips to separate geological surveys. Providing more and better data in this manner should allow industry to accelerate their drilling programs, thus increasing domestic gas supply while reducing finding and production costs.

Task 3: Assemble a broad spectrum of relevant data for wells in the selected tight gas reservoirs of the selected area of the Appalachian basin

Subtask 3.1 – Identify wells with logs (from the two State Geological Survey log libraries) that penetrate selected tight gas reservoirs of the Lower Mississippian/Upper Devonian Berea/Murrysville play, Upper Devonian Venango, Bradford and Elk plays and the Lower Silurian "Clinton"/Medina play

The availability of wireline or electric logs (e-logs) for wells penetrating the selected tight gas reservoirs in the two states was the primary selection parameter for the development of the geospatial data delivery interface. The West Virginia Geological and Economic Survey (WVGES) identified 16,211 wells with wireline logs in its log library which penetrated the associated formations of the five tight gas plays in West Virginia (i.e., the Berea, Venango, Bradford, Elk, and Tuscarora plays). The Pennsylvania Geological Survey (PGS) identified 23,977 wells with wireline logs which penetrated the associated formations of the six tight gas plays in Pennsylvania (i.e., the plays listed above, plus the Medina/"Clinton" play).

It should be noted that although the project proposal did not specifically identify the Tuscarora as one of the plays to be studied, geologists at the two state surveys decided to include that play because it is stratigraphically equivalent to the Medina/"Clinton" of Pennsylvania and because it occurs in both states. Also, any logs or cores that penetrate the Tuscarora would prove useful to both the project and to producers in their evaluation of areas for drilling or recompletion potential in any of the other, stratigraphically higher plays.

Subtask 3.2 – Determine the availability of other types of data for wells with logs; e.g., cores, slabs, thin-sections, etc

WVGES geologists identified 32 cores in the agency's core library which penetrated the five selected plays. Of those, only 11 had been slabbed and were available for photographing; logs were available and were scanned and digitized for 10 of those 11 cores. The remaining 21 cores were either not slabbed (cutting core was not part of the project plan) or exist predominantly as core chips which could not be photographed. However, logs were available and were scanned for 16 of those 21 non-photographed cores which penetrated the selected plays.

To date, nearly 50 records of core data, including core descriptions, core data analyses, and porosity-permeability cross-plots, have been entered as "documents" into the project data system.

In addition to e-logs, other types of documents were scanned. A compendium of potential project references for the six plays was developed; selected pages within some of these references were scanned for inclusion/availability on-line within the project. Among those references specifically targeted for inclusion were unpublished reports,

WVGES and federal publications, and thesis/dissertation data. Among the reference types scanned were:

- figures from the relevant chapters of ***The Atlas of Major Appalachian Gas Plays*** (also known as the *Gas Atlas;* see references) that were not able to be digitized;
- selected figures from WVGES publications, federal reports and publications, and field trip guides;
- core analysis and description data from various published or unpublished sources;
- thin-section photographs;
- relevant unpublished reports from the files of WVGES, including those reports generated for the Tight Sands Projects of the early 1980's;
- introductory material, tables of content, abstracts, conclusions, and specific maps, cross-sections, or data from some unpublished student theses and dissertations from the West Virginia University (WVU) Department of Geology and Geography.

Monthly and annual production data for individual wells are available in the WVGES oil and gas well database for the period 1979 (when production reporting first became required the by the oil and gas regulatory authority in West Virginia) through 2007. Because these data are in the database, they are available to users of this project.

Subtask 3.3 – Scan logs that haven't already been scanned

WVGES scanned e-logs for 16,211 wells identified as penetrating the plays, generating 35,254 scanned e-log files – i.e., an average of more than two individual scanned log files per well. All available e-logs for each identified well were scanned in their complete top-to-bottom intervals. The TIFF image format was selected for the scanning output because it preserves the original image, can be rather easily manipulated and incorporated into other software applications, and is commonly used as a log image format by other state geological surveys.

A standard file-naming convention for scanned e-log files was developed. The file name identifies the well API number, the log curve type(s) scanned, and the availability of log analyses or half-scale logs. The file-naming convention for both the scanned and the digitized e-logs is as follows: 10-digit API number, plus

- one-letter designation for each log curve type* (see list below) with "o" (curves without a specific designation) shown last;
- a number, if necessary, to distinguish files containing logs with the same curve types but which are distinctly different logs (such as different intervals, time frames, etc.);
- "_a" for the presence of a "Log Analysis" on the log itself, if included;
- "_h", if necessary, for reduced scale (half-scale) logs.

*Types of Log Curves

Code	Log Curve Type	Includes
c	caliper	
d	density	includes bulk density, compensated density, density, density porosity, grain density, matrix density, etc.
g	gamma ray	
i	induction	dual induction, medium induction, deep induction, spherically focused, etc.
n	neutron	neutron porosity, sidewall neutron, etc.
t	temperature	borehole temperature, differential temperature, etc.
b	cement bond	
e	photoelectric absorption	PE or Pe, etc.
l	laterolog	
m	dipmeter	
p	perforation depth control or perforate	
s	sonic or velocity	
z	spontaneous potential or potential	
o	Other**	** may include, but not limited to, curves such as audio, bit size, CCL, collar locator, continuous meter, directional survey, gas detector, guard, NCTL, Nuclear Cement Top Locator, radioactive tracer, tension

Following are several examples of file names for scanned e-logs:

- 4710900302dnietgco.tif – for a scanned log file containing density, neutron, induction, photoelectric, gamma ray, caliper, and other log curves
- 4710700803dgc_a.tif – for a scanned log with density, gamma ray, and caliper curves and a log analysis at the end of the image;
- 4701500063bsgo.tif – for a scanned log with a cement bond, sonic, gamma ray, and other log curves;
- 4701500098gto1.tig, 4701500098gto2.tif – for a well that has the same log curve types but some other distinction such as date or time.

File-naming for digitized logs was the same as for scanned logs, except that the 4-character code "**dlog**" was inserted after the API number.

Database records about the logs themselves (e.g., specific log curves available, top and bottom of each log type, availability of scanned or digitized logs, comments about the

availability of log analyses, etc.) were keyed into the Mechanical Log Catalog (MLC) data table of the WVGES oil and gas well database, in order to enable users to efficiently query the system about the availability of specific types of logs.

The PGS scanned e-logs for 23,977 wells that penetrated the 6 plays in that state, generating a total of 39,573 scanned e-log files.

Subtask 3.4 – Scan core slabs. Enter core analysis data into a database

Project staff could not scan core slabs because the technology that was previously available to us at a reasonable cost was no longer available by the time the project started. Instead, slabbed cores from the plays utilized for this project were digitally photographed at 1-foot intervals (see Subtask 3.7).

Core analysis and core description data for more than 40 wells were entered into the project database or scanned.

Subtask 3.5 – Evaluate existing data for quality management (QA/QC)

Data quality management was emphasized from the beginning of the project; it was continuous and on-going in every phase of the project that dealt with basic data.

In order to assure continuity in the management of the data and ease in the development of data queries, file-naming conventions were developed and followed for scanned e-logs, digitized e-logs, and other scanned documents and data. Previously-scanned log files were renamed in order to assure consistency of file-naming conventions. All curves for West Virginia logs were checked to identify the availability of log analyses at the end of log sections; that availability was indicated in the file name and was also coded into the WVGES MLC data table for ease in querying the availability of the data.

Instructional materials for scanning e-logs, digitizing e-logs, photographing cores, naming files, and updating MLC and Well Samples and Cores (WSC) data tables were developed. Project staff members were trained and their progress and work was monitored. Files were spot-checked on a regular basis, to assure compliance with defined procedures.

The process of determining which representative logs should be digitized started with e-logs for those wells with cores, e-logs included in the *Gas Atlas*, and those wells which provided a broader stratigraphic and geographic extent across the state (e.g., for cross-sections). Supervisory staff defined which log curves should be digitized (typically, all available curves) and trained other staff on how to digitize logs using NeuraLog software.

WVGES oil and gas well MLC database records were edited/updated for every scanned e-log to include information about specific types of logs available, specific log intervals, the presence of log analyses on the logs, and the availability of half-scale or other size logs. WSC database records were updated to include information about specific core

intervals, available core and/or cuttings/sample descriptions, and the availability of permeability data, thin-sections, or photographed core intervals. These database records will enable the development of user queries with other database fields.

Because well locations are the most basic of data utilized in these interactive digital mapping applications, a major effort was undertaken to improve the precision of "older" West Virginia well locations by digitizing those which were previously available only in a less-precise 15' scale (i.e., 1:62,500 scale) into a 7.5' scale (1:24,000 scale). Data entry staff were trained to digitize the newer locations from a variety of georeferenced maps; their work and outputs were monitored. While more than 15,000 of these older well locations were digitized to a 1:24,000 scale, not all of the 1:62,500 scale well locations were able to be converted. Work on these remaining older well locations will continue beyond this project.

A program to validate West Virginia oil and gas well data was rewritten in PL/SQL in order to assure general compliance to the agency's data coding standards and to check data across the several Oracle database tables (e.g., do the details provided in the "PAYS" record agree with the well type field in the "COMPLETIONS" record?, etc.).

Subtask 3.6 – Assemble a group of representative logs for each play and digitize the tight pay intervals to create .las files

Geographically and stratigraphically representative e-logs were selected to be digitized from the cross-sections presented in the play descriptions in the *Gas Atlas*. Additional logs were selected to be digitizing either because of the log types that they contained or to further extend the geographic availability of this type of supportive data.

WVGES staff utilized the NeuraLog software for log digitizing and digitized as many curves per log as possible. Logs were digitized by project staff for 70 West Virginia wells and operators provided .las files for an additional 34 wells, for a total 104 West Virginia wells with logs digitized for this project. PGS provided an additional 720 digitized logs files for the project.

The availability of digitized log .las (Log ASCII Standard format) files is noted in the project web site in two sections: the "Oil & Gas Well Header Data Search" (for identifying wells with digitized logs by play, county, quadrangle name, operator, surface owner, or deepest formation penetrated), and the "Well-Based E-Files (Logs)" page link (for identifying digitized logs by play, county, and/or API number).

Subtask 3.7 – Take digital photographs of available thin-sections. Photograph available core slabs

WVGES geologists identified 32 cores in its core library which penetrated the five selected plays in the state. Of those, only 11 cores had been slabbed; the remainder of the cores was either not slabbed or exist predominantly as core chips that were not photographed. The available footage of the 11 slabbed cores was digitally photographed.

Photographic images were edited and cropped to 1-foot sections, and then resized for viewing on the Internet. Large thumbnail images were created to a size of 250 pixels in width, typically placing four photos/images per web page for easy viewing. The original 1-foot image is accessible by clicking on the individual 1-foot thumbnail. Each play in West Virginia is represented by photographed core. Four cores from the Berea play were photographed with a total of 89 1-foot images, along with 2 cores from the Venango play (54 images), 1 core from both the Bradford play (12 images) and Elk play (15 images), 1 core covering the Elk play alone (45 images), and 3 cores from the Tuscarora play (359 images), for a total of 574 1-foot images. These core photographs can be viewed on the project web site at http://www.wvgs.wvnet.edu/ATG/CoresList.aspx , in the "Slabbed Core Photos" section of the web site.

The other 21 non-photographed cores are listed in a separate table on the cores web page, providing information for users who may wish to examine them in the core library. Arrangements must be made in advance to visit the core library in either state.

WVGES and PGS staff were unable to obtain privately-held thin-sections for photographing. However, photographs of some thin-sections from theses/dissertations or other references were scanned for presentation in the application.

Subtask 3.8 – Assemble relevant maps and cross-sections from the "Atlas of Major Appalachian Gas Plays" and other State Survey publications; convert these products to digital form

For each of the six plays (Berea/Murrysville, Venengo, Bradford, Elk, Medina/"Clinton", and Tuscarora), maps and cross-sections from the selected *Gas Atlas* play descriptions were scanned, cropped, georeferenced, and digitized; other tables, illustrations, and figures from the selected plays were scanned. *Gas Atlas* maps which were digitized include isopachs, isoliths, producing trends, productive gas fields/pools, outcrop and subcrop, formation limits, faults, and probable and possible resources. Maps digitized from other sources include play outlines, gas fields, oil fields, significant wells, regional thickness maps, and some structure maps. Some cross-sections were created using selected wells.

For these products, a total of 104 layers (including 6 cross-sections and 40 maps from the *Gas Atlas* and 4 maps from other sources) were digitized, as typically several layers are contained within a single map. These include:

- Berea play: 12 *Gas Atlas* layers (6 maps and 1 cross-section), and 1 other layer/map;
- Venango play: 17 *Gas Atlas* layers (5 maps and 1 cross-section), and 1 other layer/map;
- Bradford play: 15 *Gas Atlas* layers (6 maps and 1 cross-section), and 1 other layer/map;
- Elk play: 28 *Gas Atlas* layers (9 maps and 1 cross-section), and 1 other layer/map;

- Medina/"Clinton" play: 10 *Gas Atlas* layers (7 maps and 1 cross-section); and
- Tuscarora play: 22 *Gas Atlas* layers (7 maps and 1 cross-section).

More than 260 references were identified from other sources that are relevant to these plays. These other sources include university theses/dissertations, abstracts, published and unpublished reports, field trip guides, etc.

Among the data types gathered for the project's interactive mapping system are: structural, stratigraphic, paleogeographic, production, and other types of maps by specific play or regionally in general; structural and stratigraphic cross-sections; stratigraphic logs; and others.

All project images and documents are managed within a customized document management system designed and constructed in-house within an Oracle database. The Appalachian Basin Tight Gas Reservoirs Project web application which was built using .NET technology uses this document management system along with the WVGES oil and gas database to provide the user with a robust search environment for acquiring relevant material (images, documents, or data).

Task 4.0 – Devise an Internet-based geospatial data and delivery model (such as ESRI's ArcIMS) for delivery of the broad variety of data to the public

The primary objective of this task was to make data and information on the selected tight gas reservoirs available to producers and the public though an on-line, interactive geospatial data delivery model designed for public access on the Internet.

Development of this web-based application concentrated on two components: the delivery of well-based and play-based data that are searchable through user-originated queries, and interactive regional mapping that is play-based.

Subtask 4.1 – Define attribute data to be included for public access

The primary selection parameter for the project was all wells with wireline logs; the availability of cores that penetrate at least one of the selected plays also was important in that selection.

Well-Specific Database

More than 125,000 wells penetrate the six selected tight gas plays in Pennsylvania and West Virginia; the two state geological surveys have e-logs for 40,188 of those wells. All of those logs were scanned.

Project geologists from West Virginia and Pennsylvania decided to include the following data fields in the well-specific project database from which queries may be run: API

number, county name, permit number, operator name, surface owner name, farm/well number, elevation of the well, well location coordinates, 7.5' quadrangle, well type, completion date, deepest formation penetrated name, total depth, and the availability of logs and/or cores. These fields were selected because they include typical "header" data fields with which producers are familiar.

Additionally, WVGES decided to add the following data fields to the project database, to enable more robust data queries and searches: oil and gas mineral rights owner, company number, field name, and the availability of sample descriptions.

One of the goals of this project was to amass a variety of reference materials associated with these plays. Selected references, including several with limited distribution, were collected, evaluated, categorized, and – where particularly applicable to the project – scanned for presentation on the project web site. A document management system was developed within an Oracle database to manage the variety and breadth of documents, photographs, and files that were scanned for presentation in the system.

Interactive Mapping System

The attribute data accessible from the on-line interactive mapping system are briefly described below. In addition, a complete list of attribute data presented by layer is provided in Appendix A. The Appendix A compendium includes layer name, file name, data source, attribute name, attribute data type, attribute data length, and attribute description. In determining what attribute data to include, the following factors were considered: anticipated usefulness to an operator (based on discussions with operators), mapping system speed, and data availability.

- General Geography Layers: All of the general geography layers were obtained from other sources. The layers contain the attributes as obtained from the source.
- General Geology Layers: With the exception of the "All Gas and Oil Wells" layer, all of the general geology layers were obtained from other sources and contain the attributes as obtained from the source. The "All Gas and Oil Wells" layer contains basic data and attributes from the geological surveys' oil and gas well databases about the well location, owner(s), completion(s), any logs available, any cores/samples available, and plays that were penetrated.
- Play-Specific Layers and Documents (included for each of the six plays):
    - Wells that Penetrate Play
        - Pennsylvania:
        - West Virginia: Attribute data include basic data about the well location, owner(s), completion(s), any logs available, any cores/samples available, and plays that were penetrated. In addition, basic data about the pay zone is included for "Wells with Reported Pay" layers.
    - Cross-Sections

      Any attribute data that could be extracted from the cross-section image was included. In general, cross-section attribute data are

very limited and include the figure label, the cross-section label, and cross-section file name.

- Maps

  Any attribute data that could be extracted from the map image were included. In general, map attribute data are very limited and depend on the type of map. For example, play outline maps contain geometry values; field maps contain field name, producing formation, and production type; and contour maps contain contour values.

Subtask 4.2 – Design and develop an Internet-based geospatial data delivery model; design public access by tight gas play, API number, spatial attributes

The Appalachian Tight Gas Reservoirs application has two major components: the web-based data applications and the interactive mapping system. The overall project application serves as a foundation for a collection of services designed to present interactive well-based maps that can be further defined by location- and attribute-based queries, show regional data such as outline maps and cross-sections, display supplemental images such as logs and photographs, and permit image and data downloads empowering users with data that can be used to meet specific needs. Screenshots of each of the data and interactive mapping application sections, along with sample queries and results, are provided in Appendix B.

Well-Specific Database

The web-based data application was developed using the Microsoft .NET platform and uses an Oracle database on the back end to allow users to search the data system developed for the project. The data system consists of three primary datasets:

- well-specific "header"-type data for Pennsylvania and West Virginia wells, with the assignment of plays based on well penetrations;
- well-based scanned documents and images, with the assignment of plays based on well penetrations; and
- play-based scanned documents and images.

Users can navigate through the web-based data application and interactively search the system through the forms that have drop-down list boxes to select from and text boxes to fill in. All of the datasets noted above are searchable by play, geography, or several other basic data fields.

User-originated database searches can be created from any number of fields available on the search forms. For a well-header-based data search, search fields include: play; geographic extents such as county or quadrangle; type of log available; log bottom depth; the availability of scanned logs, digitized logs, sample descriptions, and/or core photos; API number; total depth; completion year; operator; surface owner; field name; deepest formation penetrated; and/or well type.

For a search of well-based e-files, search fields can include any combination of play penetrated, well API number, and data type (such as core photos, core descriptions or analyses, sample descriptions, scanned or digitized logs, or thin-section photos); results can be retrieved for viewing on-screen or downloading to a user's desktop.

For play-based searches, users can query the system for play-based documents such as reports, theses or dissertations, maps, cross-sections, stratigraphic or paleogeographic illustrations, or other types of information. Additionally, users are able to search for references by play, year published or written, or author. Results from several of the searches are returned in a grid format along with an optional link enabling the user to view the results on-screen or open the results in – and export the results to – a Microsoft Excel spreadsheet. When searching documents, images and photos, results are available for viewing online or can be downloaded to the user's desktop.

The Appalachian Tight Gas Reservoirs data application includes an interactive page for viewing photos of cores. The user can select from a table listing the cores which have been photographed, and can navigate through the large thumbnails of 1-foot intervals in sets typically displayed at four photos per page. Full-size images are available by clicking on a selected 1-foot interval. These core photos also are available for downloading.

The data application also provides an overview of the project, detailed help for using the system, links to pertinent other information available for the project (e.g., the file repository of downloads available and the WVGES well-specific ***"pipeline"*** access to all well data that they have available for West Virginia), and contact information for the project. Some functions (such as the ability to view scanned logs) are repeated within several sections of the application, in order to provide users with options for accessing data from a number of points within the entire application.

Interactive Mapping System

The Appalachian Basin Tight Gas Reservoirs web-based interactive mapping system presents well-based maps that can be further defined by location- and attribute-based queries; it also shows regional data such as play and field outline maps and cross-sections, and displays supplemental data, empowering users with extensive data that can be used to meet their specific needs.

The interactive mapping system provides access to data layers and documents categorized by play for each of the six plays included in the project. Each play contains well, cross-section, and map layers. A number of tools are available for examining the layers, including the zoom, pan, identify, and query tools. Also, layers are downloadable using the data extraction tool. Supplemental information and data may be obtained for the well layers by using hyperlinks; this supplemental information includes basic data about the well such as the API number, location, plays that were penetrated, owner(s), completion(s), any logs, any cores/samples, and any pay zones. Play-based layers are

supplemented by documents that may be accessed through the system. These documents include such items as charts, diagrams, and reports.

The initial version of the Appalachian Basin Tight Gas Reservoirs interactive mapping system was developed using ESRI ArcIMS (Interactive Map Server) software. The system is accessible by the public through two links on the WVGES web site: the project's main web page (URL: http://www.wvgs.wvnet.edu/ATG) and the interactive mapping system's page (URL: http://imsdev.wvgs.wvnet.edu/website/ATG/viewer.htm). The current plan is to eventually transfer the system to ESRI ArcGIS Server software when WVGES implements such enterprise software system-wide.

Subtask 4.3 – Gather, assemble, and populate the datasets

Well-Specific Database

The project database is a combination of in-house data from the WVGES database and data provided by the PGS. A master data table was built to identify each of the plays which each well penetrates, since many wells penetrate more than one play. Fields were added to the master table to help manage the information that was available for each well – e.g., scanned e-logs, digitized e-logs, core photos, scanned sample descriptions, etc. The database fields that were defined in Subtask 4.1 were used to create a project "header" record for each well. Well information that is displayed on-screen as the result of a system search is created "on the fly" from the WVGES database (using a database join/view) and from a separate database housing the Pennsylvania well data; the project web-based data application merges the two when the system is queried.

Project geologists identified more than 125,000 wells that penetrate the selected plays in the two states. From that base of project well data, the following additional well data were created for inclusion in the project database:

- e-logs were scanned for 40,188 of those wells which penetrate the selected plays in the 2 states (scanned e-logs for 23,977 Pennsylvania wells and 16,211 West Virginia wells);
- 11 West Virginia cores penetrating 5 plays in that state were digitally photographed, resulting in 627 photographs at 1-foot intervals within the cores;
- e-logs were digitized, creating .las files, for more than 800 wells in the selected plays in the two states (digitized e-logs for 720 Pennsylvania wells and 104 West Virginia wells); and
- available core analyses and thin-section photos were scanned; Excel spreadsheets were prepared for core analysis data for some wells.

Data of a more interpretative nature was also gathered, including:

- 569 well sample descriptions which were scanned;
- nearly 260 individual references which were identified and recorded in the system; and

- a myriad of other well-specific and play-specific data which was scanned, including: structure maps, paleogeographic maps, stratigraphic sections, cross-sections, various other kinds of maps, core descriptions, thin-sections and point counts, well sample descriptions, relevant portions of unpublished reports, and selected abstracts and conclusions from unpublished theses and dissertations.

Well-based and play-based images and documents were scanned and entries were recorded in the data system's document management system. A Microsoft .NET web-form application was built to allow staff to record data for each reference and each scanned document, to create a user-searchable file. The back end of this application has an Oracle data table to manage the variety and breadth of documents, photographs, and files that were scanned for presentation in the system.

Interactive Mapping System

A comprehensive list of the 104 layers in the interactive mapping system is given in Appendix A. All of the datasets or layers contained in the Appalachian Basin Tight Gas Reservoirs interactive mapping system were gathered or developed specifically for the project, while keeping in mind producer needs. Development of map layers specifically for this project is described in Subtask 3.8.

The interactive mapping system contains both well-specific and regional datasets organized within general geography, general geology, and play-specific folders. Well-specific layers include wells with reported pay or production, wells with core/sample data, wells with digitized logs, wells with scanned logs, and wells that penetrate the play for each of the six plays in the project. A general layer of all gas and oil wells (regardless of play) also is included. Well-based data were obtained from the PGS and WVGES.

Play-based regional layers include cross-sections and maps. What is contained within a play in the mapping system varies, as it was dependent on what was available. Play-based regional layers primarily were extracted from the *Gas Atlas*. In addition to play-based regional layers, the IMS includes a number of general regional or base layers as presented in Appendix A.

Subtask 4.4 – Develop metadata

In conjunction with the development of this GIS application, metadata were prepared for the project data types as required by FGDC guidelines (http://www.fgdc.gov/metadata/). The metadata format for the Appalachian Basin Tight Gas Reservoirs interactive mapping system datasets or layers is presented in Appendix C.

Task 5.0 – Technology Transfer

Subtask 5.1 – Demonstrate the geospatial data and delivery model

Public presentation of the project is available through the WVGES web site at: http://www.wvgs.wvnet.edu/atg/ . The "atg" or "ATG" initials are used to denote the "Appalachian Basin Tight Gas Reservoirs" project.

Presentations about the project, its developments, and its planned benefits were made to the producer community at the following meetings:

- a RPSEA regional conference, in Morgantown, WV, in February 2007;
- a meeting of the Appalachian Geological Society, in Charleston, WV, in March 2007;
- a Petroleum Technology Transfer Council Appalachian Region Workshop on "The Digital Revolution: Archive, Organize, Deliver", in Morgantown, WV, in June 2007.

The Appalachian Basin Tight Gas Reservoirs Project products were demonstrated at the 2008 joint meeting of the Eastern Section of the American Association of Petroleum Geologists (AAPG) and the Eastern Region of the Society of Petroleum Engineers (SPE). The following were provided in conjunction with that meeting:

- an exhibit booth highlighting the project was staffed for two and one-half days;
- on-demand demonstrations of the project were given using a live Internet connection, a laptop, and a projection screen;
- the booth contained posters explaining the project, and handouts were available.

Subtask 5.2 – Link the two State Geological Survey web sites to the PTTC web site and scanned log IMS-type application

The Appalachian Basin Tight Gas Reservoirs Project web site resides on WVGES servers; links are provided to this application from the WVGES and AONGRC web sites and are expected to be available from the PGS web site. At the beginning of the project, the Appalachian Region PTTC web site was to contain the project application link. This task is now assumed under the Appalachian Oil and Natural Gas Research Consortium's (AONGRC) web site (URL: http://karl.nrcce.wvu.edu). In addition, WVGES will be tracking project-related Web traffic through the use of web statistics software.

Subtask 5.3 – Advertise availability of the new web site

The Appalachian Basin Tight Gas Reservoirs Project web-based products were demonstrated and advertised at the 2008 Eastern Meeting of the American Association of Petroleum Geologists (AAPG)/Society of Petroleum Engineers (SPE) in Pittsburgh, PA, in October 2008. The meeting was attended by more than 1,300 industry and government professionals from more than 30 states and Canada. An exhibit booth highlighting the project was staffed for two and one-half days during the meeting. On-demand demonstrations of the project were given using a live Internet connection, a laptop, and a projection screen. In addition, the booth contained posters explaining the project and handouts were available.

Consideration is being given to making presentations to various industry organizations in the region during the coming year.

SUMMARY AND CONCLUSIONS

The data delivery interface developed for this project can help users to construct a digital stratigraphic framework for these plays and can enhance producers' abilities to evaluate wells in these tight gas plays. It can facilitate public access to a greater depth and breadth of useful data and information for exploration and development in these plays. These applications can be used to query for information designed to extend current areas of exploration or development for natural gas.

A "System Overview" section of the project web site presents a basic description of each of the eight sections of the web site, along with "Help" sections.

The digital database for Pennsylvania and West Virginia provides a comprehensive presentation of oil and gas well "header" data for tight gas wells penetrating the six plays: the Mississippian Berea/Murrysville play, three Upper Devonian sandstone plays (Venango, Bradford and Elk), and the Silurian Tuscarora Sandstone play in Pennsylvania and West Virginia, and the Silurian Medina/ "Clinton" play in Pennsylvania. The well-specific database includes not only basic well "header" data for more than 125,000 wells which penetrate the selected plays in the two states, but also scanned e-logs for more than 40,000 of those wells.

Among the other data types included in the database are digitized logs for more than 800 wells penetrating the selected plays, sample descriptions for more than 550 wells, 627 digital photos in 1-foot intervals for 11 cores, and approximately 260 references for these plays including numerous unpublished studies. Selected pages, core descriptions, core data, abstracts, conclusions, maps, and cross-sections were scanned from several references; these "documents" are managed by a document management system developed in-house and utilizing an Oracle database table. The scanned documents are viewable on the right-hand side of the Web browser page, if a user's web browser has either a PDF or TIFF viewer plug-in. Along with the scanned image, full reference information and scanned document information is given on the left side of the page.

In order to create their own collection of data based on their specific needs or interests, users can generate their own database queries through any of several search mechanisms: the well "header" search (including variables such as county, quad, type of log, presence of specific types of logs or cores or samples, total depth, operator, surface owner, field, well type, or deepest formation penetrated); the well-based e-file search (including searches based on county or data type, such as scanned e-logs, digitized e-logs, cores analyses, core descriptions, core photos, thin-section photos, or well sample descriptions); the play-based search (including play, data type, maps, cross-sections, etc.); or the reference search (including play, author, title, or year). Search results can be viewed on-screen or exported to Microsoft Excel spreadsheets.

The fully-functional, web-accessible, geospatial, interactive mapping system for the six tight gas plays utilizes ESRI's ArcIMS GIS software to display well-specific and play-specific regional data organized by tight gas play. In addition to the well data by play penetration, a more basic layer of all oil and gas well locations provides users with "header" data for 200,000 wells. The system allows interactive mapping by play, showing a number of query and display types.

Basic maps can be developed to display the following layers:

- geographic layers (such as state boundaries, county boundaries, 7.5-minute quadrangles, cities, roads, streams, bodies of water, public lands, shaded relief, and topographic maps);
- geologic layers (including all oil and gas wells, folds, faults, gravity data, and aeromagnetic data);
- play-specific data and documents (including wells that penetrate the play, wells with a reported pay zone in the play, wells with core or sample data, wells with scanned e-logs, wells with digitized e-logs, wells that penetrate an equivalent of that play);
- a link to the well-based data search;
- digitized cross-sections including that play;
- maps of play outlines and gas and oil fields in that play;
- maps digitized from the *Gas Atlas*;
- other maps in the play that were digitized for this project; and
- a link to the scanned documents for that play.

System tools help users develop their customized spatial queries. Wells meeting the query are displayed on the interactive map in a different color and the well-based attribute data can be displayed through a separate pop-up screen for all of the wells that meet the query criteria. Users can interactively customize maps from queries developed from any of these fields and can download results as ESRI shapefiles; data from queries can be downloaded from the database applications as Microsoft Excel files. Cross-section lines can be accessed by making the cross-section layer active and then by clicking on one of the cross-section lines with the hyperlink tool; the cross-section image is then displayed on the screen in a new window. Digitized regional maps, such as isopach, isolith, structure, field, or production maps, can also be accessed through the interactive mapping system.

In the "File Repositories" section, an HTTP server allows the user to navigate the directory structure to download or view the file(s) of interest. This provides an alternate type of direct entry into data access, for viewing and downloading of all of the data. The variety of e-files currently available include: scanned e-logs, digitized e-logs, photographs of cores, well sample descriptions, and core data and descriptions. Within each data type directory, the data are organized by county and permit number.

A link is also provided to WVGES' separate ***"pipeline"*** system for accessing all available well-specific data for more than 140,000 oil and gas wells in West Virginia. Only well-

specific queries by API number are enabled within ***"pipeline"*** at this time, with results viewable on a user's computer screen; this system does not provide wholesale system queries, nor does it provide for data download. Those features are currently available only for the tight gas plays in this project's applications.

The comprehensive project web site resides on WVGES servers and links are provided from the AONGRC and PGS web sites. It is available 24x7 for use by producers, government agencies, and the general public. Both PGS and WVGES plan to maintain the system by providing data updates in the future.

The applications developed for this project are scalable and can be extended to include additional plays in the stratigraphic column and/or additional geographic areas of the Appalachian basin. There has been notable interest among users in having these applications extended to include the Devonian shale gas plays, but they were not specifically included in the original proposal for this project.

The geospatial approach to data delivery is a proven methodology for the delivery of data to the public. It is currently being used by WVGES for detailed coal geology data in West Virginia and by the Midwest Regional Carbon Sequestration Partnership for carbon dioxide sequestration potential in a 7-state area. It also was used by AONGRC for delivery of geospatial data to their partners for the Trenton-Black River play book project. Users are now accustomed to geospatial query utilizing GIS tools, interactive mapping, and downloading results. In addition to this project, future applications in this region can include the compilation of similar information for established (i.e., Devonian Huron Shale) and emerging (i.e., Marcellus Shale) shale gas plays, and evaluation of oil fields for enhanced oil recovery and coal beds for coalbed methane potential.

The evaluation of core, e-log, stratigraphic, and production data for nearby wells can help producers develop methodologies and make decisions about the recompletion of existing wells as well as infill drilling. The value of this project is in making data more readily available to gas producers; breakthroughs in terms of scientific knowledge per se were not anticipated. Rather, the potential for breakthrough is in terms of meeting the increased demand for natural gas in the region in the near term.

REFERENCES

Roen, J.B., and Walker, B.J., eds., 1996, The Atlas of Major Appalachian Gas Plays: West Virginia Geological and Economic Survey, volume V-25, 201 p.

LIST OF ACRONYMS AND INITIALS USED

AAPG – American Association of Petroleum Geologists
AGS – Appalachian Geological Society
AONGRC – Appalachian Oil and Natural Gas Research Consortium
API – American Petroleum Institute
ATG – Appalachian Basin Tight Gas Reservoirs Project
DOE – Department of Energy
EIA – Energy Information Agency
ESRI – Environmental Systems Research Corp.
FGDC – Federal Geographic Data Committee
GIS – Geographic Information System
HTML – Hypertext Markup Language
IMS – Interactive Map Server; interactive mapping system
IOGA – Independent Oil and Gas Association
las – Log ASCII Standard (format for digitized log files)
NRCCE – National Research Center for Coal and Energy at West Virginia University
PAPG – Pittsburgh Association of Professional Geologists
PGTS – Pennsylvania Geological & Topographic Survey
PTTC – Petroleum Technology Transfer Council
SPE – Society of Petroleum Engineers
TORIS – Total Oil Recovery Information System
WVGES – West Virginia Geological and Economic Survey
WVONGA – West Virginia Oil and Natural Gas Association
WVU – West Virginia University

APPENDICES

Appendix A – Appalachian Basin Tight Gas Interactive Mapping System: Layer Attribute Descriptions

Appendix B – Appalachian Basin Tight Gas Reservoirs: Screen Shots of the Web-based Application

Appendix C – Appalachian Basin Tight Gas Reservoirs: Interactive Mapping System Metadata