Map of Assessed Shale Gas in the United States, 2012

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Map of Assessed Shale Gas in the United States, 2012

By U.S. Geological Survey National Assessment of Oil and Gas Resources Team, and Laura R.H. Biewick, compiler
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Conversion Factors

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Map of Assessed Shale Gas in the United States, 2012

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Abstract

The U.S. Geological Survey has compiled a map of shale-gas assessments in the United States that were completed by 2012 as part of the U.S. Geological Survey National Assessment of Oil and Gas Project. Using a geology-based assessment methodology, the U.S. Geological Survey quantitatively estimated potential volumes of undiscovered gas within shale-gas assessment units. These shale-gas assessment units are mapped, and square-mile cells are shown to represent proprietary shale-gas wells. The square-mile cells include gas-producing wells from shale intervals.

In some cases, shale-gas formations contain gas in deeper parts of a basin and oil at shallower depths (for example, the Woodford Shale and the Eagle Ford Shale). Because a discussion of shale oil is beyond the scope of this report, only shale-gas assessment units and cells are shown.

The map can be printed as a hardcopy map or downloaded for interactive analysis in a Geographic Information System data package using the ArcGIS map document (file extension MXD) and published map file (file extension PMF). Also available is a publications access table with hyperlinks to current U.S. Geological Survey shale-gas assessment publications and web pages. Assessment results and geologic reports are available as completed at the U.S. Geological Survey Energy Resources Program Web Site, http://energy.usgs.gov/OilGas/AssessmentsData/NationalOilGasAssessment.aspx.

A historical perspective of shale-gas activity in the United States is documented below and presented in a video clip included as a PowerPoint slideshow.

Introduction

Shale-gas activity in the United States began with the first well dug specifically to produce natural gas in 1821 in Devonian shales near the town of Fredonia, New York. A primer on U.S. shale-gas production, released in 2009, by the U.S. Department of Energy (DOE), noted that unconventional gas production now accounts for 46 percent of total U.S. gas production (U.S. Department of Energy, National Energy Technology Laboratory, 2009). In a 5-year time span (2004 to 2009), U.S. shale-gas production grew from 2 billion cubic feet per day (BCFD) to more than 8 BCFD (Stevens and Kuuskraa, 2009). The heightened interest in shale gas began with the Barnett Shale in North Texas, followed by development of the Fayetteville Shale in Arkansas, the Woodford Shale in Oklahoma, the Haynesville/Bossier Formations in Louisiana and Texas, the Marcellus Shale in the Appalachian Basin, and the Eagle Ford in Texas. Together with the Antrim Shale in Michigan and Appalachian Basin Devonian shales, these are the most active producing gas shales to date. In addition to these, others are being explored or evaluated, and some are emerging from exploration to exploitation. Each shale-gas basin is different with respect to the geologic setting and character of its gas-bearing shales, so each basin has a unique set of exploration criteria and operational challenges (U.S. Department of Energy, National Energy Technology Laboratory, 2009). As for conventional-type plays, an in-depth understanding of the geology, petrophysics, and geomechanics of a particular shale formation is essential to achieve success in exploration and development of shale gas (Durham, 2009a); however, conventional methods of production are commonly unsuitable for these continuous-type plays.

Shale Gas Defined

Shale is a fine-grained sedimentary rock, characterized by its grain size (< 1/256 mm) and fissility. It contains clay minerals and fine grains of quartz and feldspars, plus organic material, but the classification of “shale” still rests on particle size rather than mineralogy (Forgotson, 2006). Cardott (2004) defined gas shales as containing a minimum of 0.5 wt percent total organic carbon (TOC). Gas shales may be thermally marginally mature (vitrinite reflectance \( R_{\text{o}} \) 0.4–0.6 percent) to mature (0.6–2.0 percent \( R_{\text{o}} \)) and contain biogenic to thermogenic methane. Gas is generated and stored in situ in gas shales as both adsorbed (on organic matter) and as free gas (in fractures and pores), similar to natural gas in coals.

Gas shales are traditionally viewed as both source rocks and seals for stratigraphic gas accumulations (Denney, 2009). Cole and others (1987) reported that gas shales constitute source, as well as reservoir rock and seal, and that hydrocarbon migration distances within the shale are relatively short. Conventional reservoirs situated stratigraphically above or below the shale also may be concurrently charged with hydrocarbons generated by the same shale source rocks.
A Rocky Mountain region shaly source rock, the Cretaceous Niobrara, is rich in organic carbon and contains significant carbonate material. The lithology of the formation was controlled by many factors during deposition in a major marine transgression of the Western Interior Seaway, ranging from siliciclastic-rich intervals in the western part of the seaway (western Colorado) to chalk and marlstone in eastern Colorado (Longman and others, 1998). Considering the Niobrara as a fine-grained source rock also places chalks and marlstones in the category of shale plays (Hill and others, 2008).

In addition to the variety of lithologies that can be interbedded with shale-gas source rocks, some of the shale-gas formations generate gas in deeper parts of the basin but are shallower in others, for example, the Woodford Shale and the Eagle Ford Shale. Factors that have spurred the explosive growth of shale-gas plays include development of a greater geologic understanding, advances in drilling and completion techniques, and access to land and infrastructure (Stevens and Kuuskraa, 2009).

**Historical Perspective**

The earliest references to black organic-rich shale units were by French explorers and missionaries from 1627–1669, who noted occurrences of oil and gas now believed to be sourced by Devonian shales in western New York (Roen, 1993). In 1821, William Hart dug the first well specifically to produce natural gas in the United States, in the village of Fredonia on the banks of Canadaway Creek in Chautauqua County, New York. It was excavated to a depth of 27 feet with shovels by hand, and its gas pipeline was hollowed-out logs sealed with tar and rags (Hill and others, 2008). The gas was used to illuminate the town of Fredonia (Roen, 1993). Gas was discovered in Devonian and Mississippian shales in the western Kentucky part of the Illinois Basin in 1863 (Curtis, 2002). Drilling commenced in Pennsylvania in the 1850s and was extended into Ohio a decade later (Janssens and de Witt, 1976). By the 1920s, drilling for shale gas had progressed into West Virginia, Kentucky, and Indiana (Curtis, 2002), and by 1926, the Devonian shale-gas fields of eastern Kentucky and West Virginia comprised the largest known natural gas occurrences in the world (Roen, 1993).

Anecdotal accounts of gas shows and local consumption are also part of the history of settlement in the Northern Great Plains during the late nineteenth and early twentieth centuries (Shurr, 2008). Cretaceous shales crop out and (or) are in subcrops along the eastern margin of the Williston Basin in North and South Dakota. Glacial deposit aquifers above shale subcrops commonly had natural gas in sufficient quantities for domestic use in a single home to commercial use for small municipalities. Much of this gas was recognized as coming from Cretaceous shales (Wilson, 1922; as reported in Shurr, 2008).

Following the energy crisis of 1973, the onset of energy shortages and the subsequent increase in natural gas prices spurred the U.S. Department of Energy to fund a multistate cooperative program called the Eastern Gas Shales Project (EGSP) that spanned the Appalachian, Illinois, and Michigan Basins (Harper, 2008). The EGSP functioned to integrate planning and research of some 40 organizations from 15 states to exchange and evaluate information and technology to learn about the gas-producing potential of Devonian shale. The deeper shales were considered to be much less attractive targets and would remain so until gas prices increased and technology advanced enough to make drilling and completion competitive with more conventional targets (Harper, 2008).

The Federal Tax Section 29 nonconventional fuels production tax credit in the 1980s helped develop and boost the economics of marginally productive organic-rich gas shales (Stevens and Kuuskraa, 2009). This early initiative spurred development of new technologies. The credit applied to gas produced from formations classified as “tight” from wells drilled after December 31, 1979, but before January 1, 1993, and the gas being sold before January 1, 2003. Prior to 1994, the Ohio Shale (Appalachian Basin) produced the majority of U.S. shale gas, until the drilling boom in the Michigan Basin elevated the Amin Shale to the top position (Curtis, 2002). The Amin Shale was the most active U.S. natural gas play in the early to mid-1990s (Hill and others, 2008). Tax Section 29 expired in 1993; however, the state of Texas continued the tight reservoir severance tax relief, and the Barnett Shale qualifies for this tax relief, thus maintaining interest in the play (M. A. Denham, 2004, personal commun.; as reported in Martineau, 2007). Commercial gas production was established from the Mississippian Barnett Shale in the Fort Worth Basin in the early 1980s, but did not expand until the late 1990s; it is now one of the most active natural gas plays in the United States (Hill and others, 2008).

Exploration, drilling, and production of shale-gas plays such as the Barnett, Fayetteville, and Haynesville have changed the unconventional gas industry. Two technologies that enhanced shale-gas development are horizontal drilling and hydraulic fracturing (Denney, 2009), which are discussed in the following section. In addition, more is understood about the Barnett Shale after the drilling of more than 3,000 vertical wells and an increasing number of horizontal wells (Martineau, 2007). Development of the Fayetteville began in the early 2000s as gas companies that had success developing the Barnett Shale of the Fort Worth Basin identified parallels between it and the Mississippian-aged Fayetteville Shale in terms of age and geologic character (U.S. Department of Energy, National Energy Technology Laboratory, 2009).

The modern era of Marcellus Shale production in the Appalachian Basin began in 2004 when Range Resources completed the Renz Unit no. 1 well in Washington County, Pennsylvania, using large Barnett style slick-water fracturing (Wrightstone, 2009). Since 2005, the expansion of Marcellus Shale development has continued in Pennsylvania and the Appalachian Basin (Arthur and others, 2008). In 2007, after several years of drilling and testing, the Haynesville shale made headlines as a potentially significant gas resource (U.S. Department of Energy, National Energy Technology Laboratory, 2009). However, it was not until early 2008 that
operators realized that the Haynesville/Bossier Formation might be as commercially attractive as the other shale-gas plays (Railroad Commission of Texas, 2010b).

Hill and others (2008) pointed out that, whereas oil production spread rapidly from east to west across the United States, shale-gas production was much slower to develop. Focused efforts have now begun in the Rocky Mountain region; however, recent drilling experience in areas such as the Cretaceous shales of the Rocky Mountain region shows that the Barnett play concept does not translate into success in other geologic situations. The recipe for success is more complicated, in part because of a lack of understanding of the geologic processes involved (Hill and others, 2008).

Recovery Technologies

The low natural permeability of shale has been the limiting factor in the exploitation of shale gas (Denney, 2009), but the advent of horizontal drilling and hydraulic fracturing has facilitated the expansion of modern shale-gas development.

Although the first horizontal well was drilled in Texas in 1929, it was not until the 1980s that the technology was improved enough to become a standard industry practice. The technology involves drilling a vertical hole to several hundred feet above the target reservoir, then directing the drill bit through an arc until it is drilling essentially horizontally (Harper, 2008), as shown in figure 1. The advantages of horizontal wells (for example, see Harper, 2008) include (1) increases in the amount of reservoir penetrated from possibly a few tens of feet to over 5,000 feet, (2) increases in the number of vertical or sub-vertical fractures intersected, and (3) it can be used to develop hydrocarbon resources beneath sensitive areas such as wetlands and cities where a drilling rig cannot be set up. A systematic approach to well construction, data collection, and pre-fracture diagnostics is an essential component in the quest for the most effective hydraulic-fracture stimulation and the best chance to achieve commercial gas production (Bybee, 2009). M ineralogy low in ductile clays and high in brittle quartz, feldspar, and carbonate components helps promote fracturing effectiveness (Stevens and Kuuskraa, 2009).

The design process for a hydraulic-fracture treatment starts with pre-stimulation reservoir evaluation, which involves collecting field data and gaining an understanding of the character of the reservoir and of the dynamics of existing stress relations. Collected data include porosity, permeability, and lithology of the producing formation; fluid-saturation data; natural-fracture character; and current stress regimes that identify the maximum and least principal horizontal stresses (Denney, 2009). The operator creates effective permeability by fracturing the shale in a manner that connects with natural fractures. Natural fractures help propagate hydraulic fractures as planes of weakness. Large-scale natural fractures and faults are detrimental—they can limit effective horizontal lateral lengths, absorb hydraulic fracture energy, and serve as conduits for water (Kuuskraa and Stevens, 2009). Fractures must be away from faults, and need barriers to stay in-zone.

It was not until development of the Barnett Shale play in the 1990s that a technique suitable for fracturing shales was developed. This technique, called a “slick-water frac” consists of sand and large volumes of freshwater that have been treated with a friction reducer such as a gel. Slick-water fracs maximize the length of the fractures horizontally while minimizing the vertical fracture height, resulting in greater gas mobility and more efficient recovery of a larger volume of the gas (Harper, 2008).

Slide Show of Shale-Gas Production through Time

For a historical perspective of shale-gas production activity in the United States, this report includes a slide show of shale-gas production in 10-year increments from the early 1900s to 2012. Digital data were used from more than 3 million wells in IHS Energy, Inc.’s PI/Dwrights PLUS Well Data (IHS Energy, 2012). In some areas, the IHS data tend not to be complete, particularly in areas where current commercial activity is high. IHS data were supplemented with State and other well databases for the Fayetteville (Arkansas), Haynesville (Louisiana), Caney (Oklahoma) and Woodford (Oklahoma) shales.

Because of the proprietary nature of many of these databases, exact drill-hole locations cannot be shown. Therefore, the mapped area was divided into a grid of square-mile cells and the well production status was aggregated. The cells were then converted to polygons attributed to indicate the shale-gas formation. No proprietary data are displayed or included in the cell maps. All maps figures use imagery from ArcGIS Online, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey (USGS). The slideshow is available on the CD-ROM and the website (http://pubs.usgs.gov/dds/dds-069/dds-069-z/). Press the escape key (ESC) to end the slideshow, or navigate the vertical scroll bar to view a particular time frame.

Print Map

The shale-gas map is available both as a static Portable Document Format (PDF) file, and as an interactive map that is contained on CD-ROM and is accessible at http://pubs.usgs.gov/dds/dds-069/dds-069-zl. Software used to create this digital map product includes: Environmental Systems Research Institute, Inc. (ESRI) ArcGIS 9.3, Python, Adobe Photoshop CS5.1, Illustrator CS5.1, and Acrobat 7.0.

To open the hardcopy map, click on the map graphic shown in figure 2. This action opens the static map in Adobe Acrobat Portable Document Format (PDF). A dobe Acrobat Reader software must be installed to view the PDF map and is available for download at http://get.adobe.com/reader/.

The hardcopy map is designed to be plotted at a sheet size of 36” wide by 26” high. A printed map can be ordered from USGS Maps on Demand at http://store.usgs.gov.
Figure 1. Example of horizontal wells (Reproduced courtesy of EnergyFromShale.org, © the American Petroleum Institute. Used with permission).
Figure 2. Map graphic that links to the hardcopy map.
Web Services

This report includes an interactive map application as a visual analysis tool and to deliver data to the public. To access the shale-gas web service, visit the USGS National Assessment of Oil and Gas Resources website at http://energy.usgs.gov/OilGas/AssessmentsData/NationalOilGasAssessment.aspx.

Download Maps and Data

The Map of Assessed Shale Gas is available as a Geographic Information System (GIS) map and data package (both MXD and PMF formats) that is contained on CD-ROM or can be downloaded at the USGS website for this report (http://pubs.usgs.gov/dds/dds-069/dds-069-z/). The GIS allows one to visualize, question, analyze, and understand the shale-gas data in ways that reveal relations, patterns, and trends more effectively than with the static PDF map. The publishing process uses the ArcMap project (MXD) and creates a special file called a published map file (PMF). ArcGIS Publisher (ESRI, 2008a) is the extension used to create the PMF from the MXD; it packages the required data with the PMF file for easy distribution. PMFs can be viewed, explored, or printed using any ArcGIS (ESRI, 2000) desktop product, including ArcMap and the free ArcReader (ESRI, 2008b) application. Users can download and install the free ArcReader software from ESRI. To access the MXD requires ArcGIS 9.3.1 or later software (ESRI, 2000).

All data are stored in file-based geodatabase (ESRI, 2012) format (ShaleGasAUs2012.gdb, ShaleGasCells2012.gdb and BaseLayers.gdb) and shapefile format using the World Geodetic System (WGS) 1984 projection, which is a standard projection for distributing geospatial data. The polygons represent shale-gas assessment units (AU) that have been defined by the USGS, and square-mile cells are shown to represent proprietary shale-gas wells.

An AU is a mappable part of a petroleum system in which discovered and undiscovered accumulations constitute a single, relatively homogeneous population that share similar geologic characteristics. Many of the AUs overlap one another; these layers can be mapped together or individually using GIS. An important aspect of this map product is that its use does not require extensive GIS expertise or highly specialized equipment. The Metadata folder contains documentation in XML, html and text format. For the ArcGIS.com web services (formerly ArcGIS Online; ESRI, 2010), data descriptions, sources, and credits are stored as layer properties. With the ESRI World_Street_Map service, detailed data, such as railroads and airports, appear as the user zooms in at larger scales. Base reference layers included from “The National Atlas of the United States of America” (USDOI, 2008) are county boundaries, streams, and water bodies. A layer that represents geology of the conterminous United States (Shrubens and others, 1994) is included for reference, and a generalized USGS North American color shaded relief raster is included as well.

Summary

The USGS map of the principal shale-gas assessment units in the United States portrays the occurrence of this important resource in many regions of the country. Although the complexities of the geologic parameters that bear on the success of a shale-gas play in a given basin or setting may not yet be fully understood, critical knowledge is accumulating as drilling progresses and as advances are being made in engineering and completion technologies. Recent and substantial improvements in both areas have caused shale-gas plays once believed to have limited economic viability to be reevaluated. Estimates of the shale-gas resource, especially the portion that is technically recoverable, are likely to change over time as understanding of the resource characteristics increases with further advances in recovery methods.

Acknowledgments

This report is a compilation of work by many USGS geologists who defined and assessed shale-gas and chalk-gas assessment units. Thanks are extended to numerous geologists and GIS data specialists who provided critical insights and data download sites. The manuscript was technically reviewed by Christopher J. Schenk, Lawrence O. Anna, and William R. Keefer. I thank them for their thoughtful evaluations and suggested revisions. Thanks also go to the National Assessment of Oil and Gas GIS staff, led by Christopher P. Anderson, ADCM Management Services, for producing the assessment unit boundaries as GIS layers.

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