Table 9-9. Estimated original in-place oil and gas resources (total volumes) as determined from data provided by the Consortium partners.

Stratigraphic Unit	Original In-Place Resources, Total Volumes	
	Oil (MMbo)*	Gas (Bcf)*
Utica Shale	43,508	1,098,119
Point Pleasant Formation	33,050	1,745,803
Logana Member of Trenton Limestone	6345	348,476
Total for Utica Shale Play Selected Stratigraphic Units	82,903	3,192,398

* = estimated volume in the sweet spot area; sweet spot area is as defined to estimate remaining recoverable resources (Figure 9-8); MMbo=million barrels of oil and Bcf=billion cubic feet of gas

9.3 Comparison of Recoverable and Original In-Place Resources

Table 9-10. Approximate current recovery factors based on recoverable and in-place resource estimates.

Resources	Oil (MMbo)*	Gas (Bcf)*
Recoverable Resources	2611	889,972
Original In-Place Resources	82,903	3,192,398
Current Recovery Factors	3%	28%

* = estimated volume in the sweet spot area; sweet spot area is as defined to estimate remaining recoverable resources (Figure 9-8); MMbo=million barrels of oil and Bcf=billion cubic feet of gas

Based on the resource assessments to determine remaining recoverable resources and original hydrocarbon-in-place, it is expected that given current technology the play-wide oil recovery factor will be approximately 3% and the gas recovery factor will be approximately 28% in the “sweet spot” areas (Figure 9-8).

10.0 CONCLUSIONS AND IMPLICATIONS FOR PLAY DEVELOPMENT

The purpose of this chapter is to synopsize the research team’s findings and provide insight as to how the Utica Shale play may be developed in the future. Perhaps the most overarching conclusion is that this play is really neither “Utica” nor “shale,” based on the multi-disciplinary approach to reservoir characterization used in this Study. Evaluation of bulk mineralogy, TOC, carbonate content and thermal maturity data all point to an interbedded limestone and organic-rich shale interval in the Point Pleasant Formation as the preferred drilling target – a finding that is consistent with current drilling and production activity, especially in Ohio. The other particularly interesting finding is that reservoir porosity is comprised mostly of nm- to µm-scale pores that developed in organic matter during thermal maturation. Matrix porosity is minor to non-existent in these reservoir rocks.

The remainder of this chapter summarizes the results of research team's findings and interpretations regarding lithostratigraphy, depositional environment, core studies, TOC and thermal maturity, reservoir porosity, production data and trends, and resource assessments.

10.1 Lithostratigraphy

The research team adopted the following stratigraphic nomenclature for early Late Ordovician strata evaluated by the Study – the Kope Formation, Utica Shale, Point Pleasant Formation and Lexington/Trenton Formation. Trenton and Lexington are both formal formation names that have been applied to the same interval of rock. Therefore, in keeping with the previously published Trenton/Black River study (Patchen and others, 2006), we have designated this stratigraphic interval the Lexington/Trenton Formation. In some parts of the Study area, it is possible to differentiate individual members of the Lexington/Trenton based on their organic-rich or carbonate-rich but organic-poor characteristics. Formal names have been applied to these members in Kentucky – the Curdsville Member (organic-poor) and Logana Member (organic-rich) above. The section between the Logana Member and the Point Pleasant Formation is referred to informally herein as the upper member of the Lexington/Trenton Formation. Of all these strata, the most productive hydrocarbon source rocks tend to be the Point Pleasant Formation and the upper and Logana members of the Lexington/Trenton Formation.

10.2 Depositional Environment

The Upper Ordovician shale interval contains many sedimentary features, including burrowing, laminations, scour surfaces, apparent unconformities and abundant fossil assemblages. Burrows are common throughout much of the Devon Energy cores from eastern Ohio. The abundance of fossils indicates an environment that was well oxygenated much of the time. There are delicate trilobites and articulated ostracods that could not have been transported any significant distance. There also are beds composed almost entirely of strophomenid brachiopods, and this sort of monospecific accumulations of fossils is not likely to have been redistributed from some distant area.

Laminations are present throughout almost all of the organic-rich shales, as well as in the clay-rich, organic-poor shales. The laminations were probably produced by moving currents rather than variations in suspended load.

Scour surfaces are present throughout the studied interval from the Kope Formation to the Curdsville Member. They typically occur on top of finer shale facies and below coarser, grainier beds. These scour surfaces are surfaces of erosion that form due to an increase in energy. Given their frequency (mm- to cm-scale), they probably are evidence of a storm-dominated shelf environment. This means that the organic-rich faces were being deposited and preserved in an environment that was being hit with frequent storms.

There are several horizons within the cored intervals that appear to be unconformities. Two can be recognized in core by the presence of undulose surfaces: one is at the top of the upper Lexington/Trenton Formation, which is in the middle of the organic-rich zone, and the other is at the top of the Point Pleasant Formation. There also are two log markers that look like sequence boundaries at the top of the lower, organic-poor Utica that can be recognized on logs and correlated for long distances.

The depositional environment of the Point Pleasant Formation, upper Lexington/Trenton Formation, and Logana Member is a relatively shallow, probably <100 ft (<30 m) deep, storm-dominated, carbonate shelf that experienced frequent algal blooms. The organic matter in Upper Ordovician shales is mostly comprised of amorphinite, which indicates an algal source for the organic material in Utica and equivalent rocks. Cross-sections show that there was not much difference in water depth between the organic-rich and organic-poor areas of deposition. The fossils present in the limestone suggest water that was at times shallow, exposed to sunlight and well oxygenated. The storm-bedding throughout suggests something well above storm wave base. The environment may have been subject to seasonal anoxia due to the frequent algal blooms. A similar depositional model may be invoked for rocks deposited in New York and Pennsylvania, although these were not studied in the same detail.

10.3 Core Studies

A key element for potential production from shale reservoirs is TOC, and SGR core logging provides an opportunity to correlate wireline log data to TOC. As an example, the Devonian Marcellus Shale exhibits a good correlation among GR, uranium signature and TOC measurements. Unfortunately, the Upper Ordovician shales in the Study area did not exhibit this same relationship. The GR intensity for Utica/Point Pleasant rocks is dominated by the presence of potassium, and there is no correlation of GR intensity with the amount of organic matter. Our work demonstrates that TOC does not directly correlate to any radioactive material in the Utica-Point Pleasant interval.

Core studies of Ohio samples indicate show that GR tracks well with carbonate content, and regional log analyses and mapping efforts note a correlation between TOC and RHOB. Therefore, insoluble-residue analyses, RHOB log correlation, and/or petrographic techniques (as performed in this Study) may be better methods for predicting TOC in Ordovician shales.

10.4 TOC and Thermal Maturity

The TOC content of Utica/Point Pleasant and equivalent rocks is not identifiable by visual inspection (i.e., the "darkness" of samples does not correlate to the organic richness of samples). Many dark-colored shaly beds reported lower TOC than relatively light colored, limestone-rich beds within the same well and stratigraphic unit. In addition, because of the interlayered limestone/shale nature of these Ordovician formations, all have at least some nonorganic beds.

The Point Pleasant Formation – the drilling target in most of the wells completed to date – is an organic-rich calcareous shale with some limestone beds. The organic-rich units have roughly 40-60% carbonate content with TOC up to 4 or 5%. The organic matter composition is uniformly dominated by amorphinite, which indicates an algal source for much, if not most, of the organic material in these rocks.

The level of thermal maturity in the Utica/Point Pleasant shows a progression in increasing bitumen reflectance from west to east, with a very steep increase occurring in eastern Ohio. This is mainly the result of a rapid increase in depth of the Utica/Point Pleasant in this area. Ro random values from central Ohio ranged from 0.66 to 0.84%. In eastern Ohio, values range from 0.94 to 1.43%. Collectively, the Upper Ordovician shale in central Ohio has a level of thermal maturity in the lower to middle part of the oil window. In northeastern Ohio, the Upper Ordovician shale has a level of thermal maturity that includes the middle and upper portions of the oil window, the wet gas window and the lower part of the dry gas window. The Utica/Point Pleasant in western Pennsylvania has a level of thermal maturity that increases basinward, ranging from the upper part of the oil window to the top of the dry gas window.

CAI analyses were prepared for samples from 10 wells in Ohio. These results were used in conjunction with those of Repetski and others (2008) to prepare an updated CAI map for Upper Ordovician shales in Ohio. CAI values range from 1 to 2.5, with a trend of increasing maturity basinward.

10.5 Reservoir Porosity

Petrographic studies indicate there is little to no matrix porosity in Utica/Point Pleasant rocks, and standard SEM imaging has confirmed the tight nature of the shale matrix in these rocks. SEM analyses of ion-milled samples, however, illustrate various pore types and sizes. Pore types include phyllosilicate framework pores (due to presence of clay mineral platelets in various orientations or state of compaction), dissolution pores (from the dissolution of carbonate minerals) and organic matter pores (resulting from out-migration of hydrocarbons). Pores vary in size, and from location to location, but generally range from tens or hundreds of nm to as much as 1 µm or more. Based on these observations, we interpret the organic matter pores to be the dominant contributor to hydrocarbon production in the Utica/Point Pleasant play.

10.6 Production Data and Trends

Since the Utica Shale play began in 2011, a significant drilling and production increase has occurred. By May 2014, approximately 1470 permits have been issued to drill horizontal wells to the Upper Ordovician Utica/Point Pleasant horizon, mainly in Ohio, but with approximately 245 in western Pennsylvania and 11 in the northern panhandle counties of West Virginia. In 2013 over 3.6 MMBbl oil and 100 Bcf gas were produced from 352 wells. These volumes represent 45% of the total oil and 58% of the total gas produced in Ohio, underscoring the importance and magnitude of this play. The total reported cumulative production for the Utica/Point Pleasant from 2011 through 2013 in Ohio was approximately 4.3 MMbbl oil and 115.3 Bcf gas from 352 wells.

A northeast-southwest trend of higher production is seen extending through Columbiana, Carroll, Harrison, Belmont, Noble and Monroe counties in the liquids-rich area. The 10 best producing wells were in Harrison, Belmont, Noble and Monroe counties. Results have been less encouraging to the north and west of these areas. Trumbull County has shown lower producing rates, consistent with recent announcements by BP and Halcon that they are terminating Utica drilling in this area. Thus far, drilling farther west in the updip portion of the oil window also has produced less encouraging results, as evidenced by nonproductive Devon wells drilled in Coshocton, Knox, Medina, Wayne and Ashland counties. A northeast-southwest trend separating the oil window from the gas window is visible from GOR mapping of quarterly production data.

10.7 Resource Assessments

Using a probabilistic (USGS-style) method, we have calculated the Utica Shale play to contain mean, technically recoverable resources of 1960 MMbo and 782.2 Tcf gas. Using a volumetric method, it was determined that original oil-in-place is approximately 82,903 MMbo while the