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ENERGY RESOURCE POTENTIAL OF THE MESOZOIC BASINS IN VIRGINIA

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Energy Resource Potential of the Mesozoic Basins in Virginia

ABSTRACT

The energy resource potential of the Mesozoic basins in Virginia has been recognized for at least 260 years. The greatest production of these resources has been in the Richmond basin. Over 8 million tons of coal were mined there between 1748 and 1927. No crude oil or natural gas has been produced from the Mesozoic basins in Virginia, but at least 13 companies drilled hydrocarbon exploration wells in the basins between 1910 and 1995. The geologic models and hydrocarbon potential of the Mesozoic basins in Virginia, both onshore and offshore in State-administered waters, were recently updated.

The information in this report was compiled for and presented to the participants of the 2008 Southeastern U.S. Mesozoic Basins Energy Resources Potential Workshop held in Charlottesville, Virginia. This workshop was sponsored by the U.S. Geological Survey and the Virginia Department of Mines, Minerals and Energy. The U.S. Geological Survey and the Virginia Department of Mines, Minerals and Energy hosted the subsequent 2009 Southeastern U.S. Mesozoic Basins Energy Resources Potential Workshop in Charlottesville. The U.S. Geological Survey sponsored the Northeastern Mesozoic Basins Energy Resources Potential Workshop in 2010, which was hosted by the New Jersey Geological Survey in Trenton, New Jersey.

In 2012, the U.S. Geological Survey published a new assessment of the undiscovered oil and gas resources of the East Coast Mesozoic basins of the Piedmont, Blue Ridge Thrust Belt, Atlantic Coast Plain, and New England Provinces. The Taylorsville, Richmond and Dan River-Danville basins, which are wholly or partially in Virginia, were included, but the other exposed and buried basins in Virginia were not assessed. The potential reservoirs in the basins that were assessed are continuous accumulations in lithologies that include sandstone, mudstone, and coal. It was estimated that these accumulations are most likely to contain natural gas with associated natural gas liquids.
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INTRODUCTION

The U.S. Geological Survey (USGS) completed a national assessment of oil and gas resources in 1995 (U.S. Geological Survey 1995a, 1995b, 1995c), which was the last comprehensive assessment for the onshore area and state waters of the United States. This assessment described the East Coast Mesozoic Basins play as a hypothetical play including exposed and buried basins, both onshore and offshore, that occur in a northeasterly alignment along the eastern continental margin from northern Florida to Nova Scotia. The undiscovered, technically recoverable hydrocarbon resources were estimated to be 348.2 billion cubic feet (bcf) of natural gas in conventional reservoirs for the East Coast Mesozoic Basins play (U.S. Geological Survey, 1995a).

In 2012, the USGS published a new assessment of the undiscovered oil and gas resources of the East Coast Mesozoic basins of the Piedmont, Blue Ridge Thrust Belt, Atlantic Coast Plain, and New England Provinces (Milici and others, 2012). USGS reported that the mean undiscovered technically recoverable hydrocarbon resource is 3,860 bcf of gas and 135 million barrels of natural gas liquids (Mbngl) in continuous accumulations in the entire East Coast Mesozoic Basins play. The Taylorsville, Richmond, and Dan River-Danville basins, which are wholly or partially in Virginia, were included in the assessment, but the other exposed and inferred buried basins in Virginia were not assessed. The combined mean resource potential for the three assessed basins is 1,324 bcf of gas and 48 Mbngl.

This report summarizes the geology, history of fossil fuel production, energy resource potential, and availability of the energy resources in the Mesozoic basins in Virginia. Renewed interest in exploration of the basins may be generated by analyzing data acquired since 1995, evaluating the effect of production techniques in use today for continuous reservoirs, and applying improved modeling techniques to improve the estimates of energy resource potential of Mesozoic basins in Virginia.

GEOLOGIC OVERVIEW

During middle Triassic time, about 230–240 million years ago, the super-continent of Pangea began to break apart, forming rift basins which filled with fresh-water fluvial and lacustrine continental sediments. These sediments became deformed as the earth’s crust arched upward during the earliest phase of the opening of the proto-Atlantic Ocean. Initially, these synrift half-graben basins developed near mountain ranges that existed along what would become the eastern coast of North America. Normal and strike-slip faulting occurred along pre-existing zones of weakness, creating multiple depositional basins. An early Jurassic rifting phase was interrupted by basin inversion, uplift and erosion, and was influenced by compressional forces (Withjack and others, 1998). This was followed in the middle Jurassic by continued rifting followed by regional subsidence. Eventually seafloor spreading and opening of the modern Atlantic Ocean separated what would become North America from what is now Europe.
and North Africa. Post-rift Mesozoic and Cenozoic sediments now cover many of the early Mesozoic basins in the Atlantic Coastal Plain region and offshore areas. Figure 1 shows the generalized locations of the exposed and inferred buried basins from South Carolina to Massachusetts.

Figure 1: Major U.S. East Coast Mesozoic basins (modified from J.P. Smoot, written communication (2008); LeTourneau (2003); and U.S. Geological Survey (1995c)).

Correlations of the Triassic and lower Jurassic formations in the various rift basins on the U.S. east coast have been facilitated by stratigraphic studies of fossils, biostratigraphic data, and paleomagnetism. Collectively, these formations make up the Newark Supergroup, the name applied to formations in the exposed basins along a northeast trending belt from South Carolina to Nova Scotia (Van Houten, 1977; Olsen, 1978; Olsen and others, 1978). Figure 2 illustrates the results of studies correlating and comparing the formations and lithologies between the largest exposed basins. All of the basins contain Triassic-age sedimentary rocks, including sandstones, shales, and coals that are intruded by Jurassic-age diabase dikes. The Culpeper basin and basins to the north also contain Jurassic-age sedimentary rocks, as well as Jurassic-age basalt flows.

Figure 3 shows the locations of the exposed and inferred buried basins in Virginia relative to the physiographic provinces. The exposed basins are all located within the Piedmont province, and Mississippian, Cambrian, and Proterozoic metamorphic and igneous rocks surround the Mesozoic sedimentary rocks in the basins. The exposed Mesozoic basins include the Culpeper, Barboursville, Scottsville, Danville, Farmville, Briery Creek, Roanoke Creek,
Randolph, Scottsburg, Richmond, and a portion of the Taylorsville. All of the basins in Virginia contain Triassic-age sedimentary rocks. The inferred basins are all located beneath sedimentary strata of the Coastal Plain province or are in the near offshore marine area.

Figure 2: Correlative stratigraphy of the largest exposed Mesozoic basins (modified from J.P. Smoot, written communication (2008); and Schlische (2003)).

Wilkes and others (1989) provides the most recent compilation of the distribution of the Mesozoic basins in Virginia, including exposed and inferred onshore basins, and the offshore area adjacent to Virginia. Their report includes information from 227 hydrocarbon exploration wells, water wells, and other exploration holes that were drilled prior to 1989. Ninety-seven of these drill holes encountered Mesozoic-age rocks. Available seismic, aeromagnetic, gravity, and aeroradiometric data, both onshore and offshore, together with the drill hole data were used in their interpretation of the locations and extent of the Mesozoic basins.
Figure 3: Map of the exposed and inferred buried Mesozoic basins in relation to the physiographic provinces of Virginia. The names of the exposed basins are shown, as well as the names given to some of the inferred basins (modified from Wilkes and others, (1989)).

**FOSSIL FUELS EXPLORATION AND PRODUCTION**

Between 1748 and 1927, over 8 million tons of coal were produced in the Richmond basin (Wilkes, 1988). Minor amounts of coal were also mined from the Farmville (Wilkes, 1982), Briery Creek (Wilkes, 1987), and Taylorsville (Weems, 1980) basins. There is no current coal production from any of the Mesozoic basins in Virginia.

Although the rock formations in the Mesozoic basins in Virginia have the potential for both coalbed methane and natural gas from conventional traps, there has been no reported production. The Mesozoic basins have experienced several periods of exploration, with 36 hydrocarbon exploration wells drilled by at least 13 different companies between 1910 and 1995. The Richmond basin, located in parts of Goochland, Henrico, Chesterfield, Powhatan, and Amelia counties, is as much as 7,100 feet deep and contains non-marine Triassic sedimentary
rocks including lacustrine shales. A normal fault bounds the western side of the basin (Wilkes, 1988). Between 1930 and 1986, nine exploration wells were drilled by Merrill Natural Resources, Inc., Shore Exploration, and Richmond Syndicate that encountered oil and gas shows between the depths of 775 and 3,056 feet. These wells, however, did not encounter a reservoir of gas or oil large enough to be economically developed.

In 1989 and 1990, Amoco Production Company drilled and cored six holes to test the coalbed methane potential of the Richmond basin. These core holes encountered coals at depths ranging from 1,200 to 2,928 feet below the ground surface. Analyses showed that the coals had sufficient natural gas content and saturation for commercial potential. The seam thicknesses and net coal thicknesses were variable between the core holes, indicating a complex structural and depositional history for the formations. Due to the uncertainty regarding the extent of the coal beds, Amoco decided to not pursue the development of these resources (Knox and others, 1992).

The Taylorsville basin is mostly covered by Cretaceous and younger sediments of the Coastal Plain in Virginia and Maryland. The southern part of the Taylorsville basin is exposed in Hanover County, and is one of the few basins where outcrop information has been integrated with well cuttings, wireline logs, and seismic reflection profiles (LeTourneau, 2003). Exploration wells drilled between 1968 and 1986 penetrated Triassic sedimentary rocks, indicating the basin is at least 9,900 feet deep. In the 1980s, Texaco, Inc., drilled six core holes and three wells to evaluate the basin for petroleum potential. Four exploration wells drilled in the portion of the basin that is covered by Coastal Plain sediments had indications of the presence of oil and natural gas, but did not encounter a reservoir of gas or oil large enough to be economically developed.

Information from seismic data, water wells, hydrocarbon exploration wells, and core holes suggests that at least four distinct basins are buried underneath the Coastal Plain of Virginia. According to Costain and Coruh (1989) and Wilkes and others (1989), the thickness of the Mesozoic sedimentary rocks in the inferred basins ranges from 100 feet to 13,000 feet beneath 1,300 to 5,000 feet of Cretaceous and younger sediments. There have been no reports published regarding the thermal maturity or organic richness of the potential source rocks in these basins.

Based on seismic and other geophysical data, Bayer and Milici (1987) proposed the existence of Mesozoic basins on the outer continental shelf (OCS) of the Atlantic Ocean offshore of Virginia. Figure 3 shows the locations of the two basins inferred in the Virginia offshore area. These two basins are estimated to contain at least 13,000 feet of Triassic to lower Jurassic rock formations beneath 6,000 to 12,000 feet of younger sediments. No wells have been drilled into the rock formations of these two basins. Further exploration will determine whether there are reservoirs large enough to be economically developed in these offshore basins.
ENERGY RESOURCES POTENTIAL

According to Withjack and others (1998), the rifting phase of eastern North America was interrupted by compression, basin inversion, uplift, and erosion during the early stages of sea-floor spreading in the early Jurassic. Inversion created both extensional and compressional structures that may have served to trap hydrocarbons. Inverted basins, however, experienced uplift and erosion that may have suspended the generation and maturation of hydrocarbons, or removed reservoir and source rocks altogether. The relative timing of these events determined the distribution and quantity of hydrocarbons preserved in the rift basins. Studies performed on some of the exposed basins show that each basin has been affected by these regional tectonic events at different times. Therefore, the estimated hydrocarbon resource potential of each of Virginia’s Mesozoic basins is unique.

Geochemical analyses, including vitrinite reflectance, were performed on cores and cuttings from six core holes and three wells drilled for hydrocarbon exploration in the Taylorsville basin. Analyses of cores and cuttings from six of the core holes and exploration wells confirmed the presence of hydrocarbon source rocks in the Taylorsville basin (Malinconico, 2003a). The gray to black siltstones and shales that were deposited in a deep lake environment have measured vitrinite reflectance values from 0.48 to 2.94 %Ro, indicating a thermal maturity range from immature, in the oil window, and into the dry gas window (Malinconico, 2003a). Malinconico (2003b) calculated geothermal gradients during latest Triassic time that ranged from 40 to 55 degrees Celsius per kilometer, west to east across the basin. This high geothermal gradient, caused by elevated heat flow over the Alleghanian orogenic metamorphic/thermal belt, may have heated the kerogens and formed hydrocarbons before conventional traps were created to capture and preserve the hydrocarbons. Malinconico (2003a) used sedimentation rates for two Taylorsville boreholes to suggest that rifting and sediment accumulation ceased before the beginning of the Jurassic. Malinconico further used linear regression of the reflectance profiles from these boreholes back to 0.2%Ro to estimate that between 2,800 and 8,500 feet of Triassic sediments were eroded before deposition of post-rift strata. If the Taylorsville basin underwent compression and uplift that created traps for hydrocarbons, they may have been eroded during the latest Triassic.

Geochemical analyses of cuttings from one exploration well in the Richmond basin indicate that the mixture of Types II and III kerogen found in the shales there is mostly gas-prone. The total organic carbon content measured from six samples from one corehole is as high as 8% by volume. The vitrinite reflectances measured in these six samples indicate the potential source rocks are in the oil thermal maturity window. Vitrinite reflectances versus depth profiles measured in four boreholes in the Richmond basin were lower than the thermal maturity profiles in some of the Taylorsville basin boreholes (Malinconico, 2002). Therefore, the Richmond basin must have had a lower geothermal gradient during the Triassic than the Taylorsville basin. Whether this was beneficial in the timing of hydrocarbon generation in relation to entrapment is uncertain.
RESOURCE ASSESSMENTS

In 1995, the USGS published the National Assessment of United States Oil and Gas Resources report, in which undiscovered technically recoverable resources for the Piedmont Province (U.S. Geological Survey, 1995c) were estimated. Within the Piedmont Province, the East Coast Mesozoic Basins play was listed as a conventional hypothetical play. Hypothetical plays are those that are defined by geologic information, but have no documented accumulations (U.S. Geological Survey, 1995b). In 1995 there were no known commercial accumulations of oil or gas in the East Coast Mesozoic Basins. The play encompassed all of the Mesozoic basins in the Piedmont, Blue Ridge Thrust Belt, Atlantic Coast Plain, and New England Provinces on the East Coast of the United States. The USGS estimated that the East Coast Mesozoic Basins play could contain undiscovered technically recoverable resources of about 350 bcf of natural gas in conventional reservoirs (U.S. Geological Survey, 1995a). No estimates were given for resources in unconventional assessment units, such as coalbed methane or shale gas reservoirs.

In 2012, USGS published a new assessment of the undiscovered oil and gas resources of the east coast Mesozoic basins of the Piedmont, Blue Ridge Thrust Belt, Atlantic Coast Plain, and New England Provinces (Milici and others, 2012). The new estimate predicted 3,860 bcf of gas and 135 Mbngl in undiscovered resources situated in continuous accumulations. The source rocks for the predicted hydrocarbons in the basins are proposed to be gray and black shales, and coal beds. The reservoirs are predicted to be lithologies ranging from conglomerates and sandstones to mudstones, shales, and coal beds. The Taylorsville, Richmond, and Dan River-Danville basins, which are wholly or partially in Virginia, were included, but the other exposed and inferred buried basins in Virginia were not assessed. The combined mean resource potential for the three assessed basins is 1,324 bcf of gas and 48 Mbngl. USGS assigned 57% of the Taylorsville basin resources to Virginia, and 55% of the Dan River-Danville basin resources to Virginia. Thus, the mean resource potential of the Mesozoic basins in Virginia is approximately 850 bcf of gas and 32 Mbngl.

Established in 1982, the U.S. Department of the Interior, Minerals Management Service (MMS) managed Federal mineral and hydrocarbon resources on the OCS, including the area seaward of a line three nautical miles from the coast of Virginia. For hydrocarbon resources in the OCS, the MMS was responsible for all activities from lease issuance to decommissioning of platforms. In 2001, MMS published their estimate of the oil and natural gas potential for the U.S. offshore areas including the Atlantic OCS (U.S. Minerals Management Service, 2001). No resources were assigned to the synrift sedimentary rock formations in the inferred Mesozoic basins in the Virginia offshore area.

MMS was renamed in 2010, becoming the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE). In 2011, BOEMRE was reorganized into two organizations, which were named the Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE). The responsibilities for oil and gas leases, resource assessments, renewable energy development, and environmental studies and reviews were assigned to BOEM in 2011. In the most recent assessment of the Atlantic OCS, BOEM estimated the mean undiscovered technically recoverable resource potential for the Triassic-Jurassic Rift Basin play was 0.49 billion barrels of oil (bbo) and 1.37 trillion cubic feet.
(tcf) of gas (U.S. Bureau of Ocean Energy Management, 2012). All of the resource potential was assigned to an area in the North Atlantic Planning Area, and none of this resource potential was assigned to the area offshore of Virginia.

**ACCESSIBILITY**

Most of the Richmond basin, all of the Taylorsville basin, and all of the buried Mesozoic basins in Virginia are in the Tidewater area as defined by the Code of Virginia 10.1-2101 (Virginia General Assembly, Legislative Information System, Code of Virginia, 2005). In Tidewater, drilling is prohibited within 500 feet of the shoreline or in the waters of the Chesapeake Bay and its tributaries. To operate in Tidewater where it is not prohibited, an operator is required to submit an Environmental Impact Assessment (EIA) with the application for a permit to drill for natural gas or oil to the Virginia Department of Mines, Minerals and Energy (DMME). This entity then notifies the Virginia Department of Environmental Quality (DEQ) to coordinate the review of the EIA. The Code of Virginia 62.1-195.1 (Virginia General Assembly, Legislative Information System, Code of Virginia, 1994) lists the requirements that must be followed in order to drill or produce gas and oil in the Tidewater area of Virginia.

There have been no offshore lease offerings in Federal waters in the Atlantic since the early 1980s, and there are no active leases. In 2007, the MMS published its five-year leasing program for 2007–2012, in which it scheduled one potential lease offering (Lease Sale No. 220) in Federal waters off the coast of Virginia in 2011 (U.S. Minerals Management Service, 2007). The area of offshore Virginia proposed for the 2011 lease sale extended 190 miles from the coastline. But the Norfolk basin and half of an unnamed basin were within a buffer zone that extended 50 miles from the coast that was excluded from the proposed lease sale area. The edge of the continental shelf is about 65 miles from shore, where the water depth is 650 feet (200 meters). Subsequent considerations by the Federal government, including concerns raised by the U.S. Department of Defense, supported a decision to not schedule any offshore lease sales in the Mid-Atlantic or South Atlantic Planning Areas through 2012. An environmental review by the BOEM was initiated that could support approval of new seismic and other survey activity as early as 2013.

**CONCLUSIONS**

The most recent hydrocarbon resource assessment for the U.S. East Coast Mesozoic Basins play indicates the mean undiscovered technically recoverable hydrocarbon resource in five of the basins is 1,324 bcf of gas and 48 Mbngl in continuous reservoirs, of which 850 bcf and 32 Mbngl is potentially located in Virginia. For reference, in 2011, 151 bcf of gas were produced in Virginia (U.S. Energy Information Administration, 2012a), and 352 bcf of gas were delivered to consumers in Virginia in 2011 (U.S. Energy Information Administration, 2012b). BOEM estimated that there is no undiscovered technically recoverable hydrocarbon resource potential of inferred buried Mesozoic basins in the offshore Virginia area. As State and Federal agencies evaluate changes to energy policies, it is appropriate that the energy resource potential of the exposed and inferred buried onshore Mesozoic basins be considered. The USGS
assessment of the resource potential of the East Coast Mesozoic Basins play (Milici and others, 2012) provided an updated report that incorporated current technology and industry practices of the development of continuous reservoirs.

Since the last geologic study of the basins was completed (Wilkes and others, 1989), additional well and seismic data have been gathered, and some of this data is available to DMME. Data from three exploratory hydrocarbon wells drilled between 1992 and 1995 is available, as well as data from at least 30 water wells that were drilled since 1989 to depths that may have encountered Mesozoic formations. This information was utilized for the recent USGS resource assessment, and will facilitate a refinement of the interpretation of the characteristics of the buried basins in the coastal plain of Virginia.

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Virginia General Assembly, Legislative Information System, Code of Virginia, 1994, Title 62.1 Waters of the State, ports and harbors, Chapter 20 Miscellaneous Offenses, 62.1–195.1 Chesapeake Bay; drilling for oil or gas prohibited: http://leg1.state.va.us/cgi-bin/legp504.exe?000+cod+62.1-195.1


