BLUE RIDGE THRUST BELT (068), PIEDMONT PROVINCE (069), ATLANTIC COASTAL PLAIN PROVINCE (070), ADIRONDACK PROVINCE (071), AND NEW ENGLAND PROVINCE (072)

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The Blue Ridge Thrust Belt (068), Piedmont Province (069), Atlantic Coastal Plain Province (070), and the New England Province (072) are generally east of the Appalachian Basin Province (067), while the Adirondack Province (071) is to the north. Except for the Appalachian Basin, these provinces do not produce oil or gas and are not currently viewed as prospective for oil and gas. Consequently, they will be treated very briefly here. Three hypothetical conventional plays were defined and are discussed in detail.

The Blue Ridge Thrust Belt Province (068) underlies parts of eight States from central Alabama to southern Pennsylvania. Along its western margin, the Blue Ridge is thrust over the folded and faulted margin of the Appalachian basin, so that a broad segment of Paleozoic strata extends eastward for tens of miles, buried beneath these subhorizontal crystalline thrust sheets (Harris and others, 1981). At the surface, the Blue Ridge consists of a mountainous to hilly region, the main component of which are the Blue Ridge Mountains that extend from Georgia to Pennsylvania. Surface rocks consist mainly of a core of moderate- to high-rank crystalline metamorphic or igneous rocks, which, because of their superior resistance to weathering and erosion, commonly rise above the adjacent areas of low-grade metamorphic and sedimentary rock. The province is bounded on the north and west by the Paleozoic strata of the Appalachian Basin Province and on the south by Cretaceous and younger sedimentary rocks of the Gulf Coastal Plain. It is bounded on the east by metamorphic and sedimentary rocks of the Piedmont Province (069).

Geologically, the Piedmont Province (069) consists of a variety of sharply folded and faulted supracrustal metasedimentary and plutonic intrusive rocks that are generally younger than the 880-1,000 million year old rocks of the Blue Ridge Thrust Belt Province (068) to the west. In addition, thick sections of Early Mesozoic sedimentary rocks containing intruded and extruded mafic igneous rocks fill rift basins that are widely distributed in the Piedmont and beneath the Atlantic Coastal Plain. The metasediments within the Piedmont Province may be as young as Ordovician. These Precambrian through lower Paleozoic crystalline rocks extend to the east under the Upper Jurassic through Cenozoic sediments of the Atlantic Coastal Plain Province.

The Atlantic Coastal Plain Province (070) is comprised of Upper Jurassic through Cenozoic sedimentary rocks which overlie much older Precambrian through lower Paleozoic basement rocks. A number of

Mesozoic rift basins, containing Late Triassic and Early Jurassic sedimentary rocks, are located within the Atlantic Coastal Plain Province and occur beneath a major regional unconformity, the break-up unconformity of Schlee and Klitgard (1986). The Piedmont and Atlantic Coastal Plain Provinces produce neither oil nor gas.

The Adirondack and New England Provinces (071 and 072) include sedimentary, metasedimentary, and plutonic igneous rocks, mainly of Cambrian and Ordovician age, similar lithologically to rocks in the Blue Ridge and Piedmont Provinces (068 and 069) to the south. The uplifted, nearly circular Adirondack Mountains consist of a core of ancient Precambrian rocks that are surrounded by upturned Cambrian and Ordovician sedimentary rocks. Minor shows of gas have been reported in lower Paleozoic carbonate rocks in the folded and thrust-faulted sequence of western Vermont; however, no commercial oil or gas production has been established anywhere in these provinces.

In these five provinces, three conventional hypothetical plays were defined: Southern Appalachian Sub-Thrust Sheet Play (6801), Champlain Valley/Sub-Taconic Allocthon Play (6802), and East Coast Mesozoic Basins Play (6901).

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PLAYS

6801. SOUTHERN APPALACHIAN SUB-THRUST SHEET PLAY (HYPOTHETICAL)

This hypothetical high-risk play is located along or beneath the leading edge, or toe, of the southern Appalachian thrust sheet in the Blue Ridge Thrust Belt Province, chiefly in eastern Tennessee and southern Virginia.

Reservoirs and source rocks. Conodont color alteration indices (Orndorff and others, 1988) indicate that thermal metamorphism in the fenster region of the Great Smoky Mountains in Tennessee is within the range for the generation of dry gas. Because of considerable amounts of structural deformation, however, only the lower part of the Paleozoic section appears to be preserved beneath the thrust sheets. Potential carbonate reservoirs are commonly recrystallized within the area and slaty cleavage occurs in the Ordovician black shales that are most likely to serve as source beds. Thus, there seems to be very little potential for good quality reservoirs or source beds in the region.

Exploration status. The hydrocarbon production nearest to the southern Blue Ridge occurs in the Early Grove field in the Appalachian Basin Province in the central part of the southern Virginia Valley and Ridge, and in the Appalachian Plateau regions of western Virginia and northeastern Tennessee. However, this production is 50 to 100 miles away and in an area greatly different geologically from the area of this play, which is adjacent to and beneath the southern Appalachian Blue Ridge thrust sheet. The intervening Valley and Ridge physiographic province is structurally complex and, although untested, is considered to have little resource potential because of little potential for good quality reservoirs and source beds.

Resource potential: This hypothetical play was not formally assessed because of the general lack of evidence for potential source rocks and reservoirs.

6802. CHAMPLAIN VALLEY/SUB-TACONIC ALLOCHTHON PLAY (HYPOTHETICAL)

The play occurs in the Cambrian and Ordovician sequence that occupies the footwall of the Taconic overthrust and associated thrust sheets. It is dependent, to a great extent, on fracture porosity in Lower Paleozoic carbonate reservoir rock, including the Trenton, Black River, Utica, and Lorraine Formations, both in the exposed part of the footwall and/or in its extension into the subsurface beneath the Taconic allochthon.

Bayer (1988) reports that five wells were drilled in the northern part of the region, in Grand Isle, Franklin, and Chittenden counties, Vermont. One of these is reported to have a show of oil. Because more recent drilling has yielded shows of gas in southern Washington County, New York (Guo and others, 1990), the Champlain Valley Sub-Taconic Allochthon play (6802) is extended southward for a distance of 150 miles, from the Canadian border along the Champlain Valley into the region of the Taconic Overthrust, for the purposes of this assessment.

The stratigraphy and geologic structure of the Quebec Lowlands, Canada, is sufficiently similar to the stratigraphy and structure of northeastern New York and northwestern Vermont to be used as an analog for estimating the hydrocarbon resources of the Champlain Valley region. In addition, the Lower Paleozoic stratigraphy in the northeastern part of the Finger Lakes region along the southern and eastern shores of Lake Ontario to the west of the Adirondack Mountains is similar to the lower part of the Paleozoic section in the Champlain Valley. Of the two areas, the geology of the Quebec Lowlands is structurally more similar to that of the Champlain Valley than is the geology of the northwestern Finger Lakes region. Nevertheless, because of stratigraphic similarities, the northwestern Finger Lakes region is also used here as an analogue for hydrocarbon accumulations in the lower part of the Paleozoic section in the Champlain Valley.

The Quebec Lowlands are situated in the Province of Quebec, Canada, generally between Quebec and Montreal in an area that is approximately 200 miles long and 50 miles wide. Gas was first discovered in shallow wells drilled in the early 1900's by farmers who were attempting to find water (Dykstra, 1992). The Point du Lac gas field was discovered in 1955 and produced gas commercially from 1962 to 1976. This field is unusual in that it produced gas from unconsolidated Pleistocene sands that were charged from black shale source beds in the underlying Utica and Lorraine Formations. The St. Flavien gas field was discovered in 1972 in the overthrust area by Shell Oil Company. A subthrust well by Shell Oil Company, Shell St. Simon No. 1, tested the Beekmantown at about 420 MCFPD, which is not commercial in an area of complex geology and moderate drilling depths (Dykstra, 1992). Bow Valley Industries *et al* St. Simon No. 1 tested a lower dolomite of the Beekmantown Formation at about 13,000 feet and found a show of gas that was 93 percent carbon dioxide.

In general, the Quebec Lowlands area trends to the northeast and is underlain by a Cambrian and Ordovician stratigraphic sequence of siliciclastic and carbonate rocks (Beiers, 1976). Structurally, the Quebec Lowlands are divided into four zones from west to east, the platform zone, the external zone, the internal zone, and the nappe zone. Normal faults, active during the earliest Paleozoic, are characteristic of the platform zone. The lowermost Paleozoics of the platform zone are bordered on the northwest by a basement of crystalline rocks and on the east by thrust sheets that were emplaced upon the platform during the Taconic orogeny. The external, internal, and nappe zones mark the progressive increase of the deformation of the Quebec Lowlands from west to east. The external zone is characterized by subhorizontal thrust faulting within the Utica/Lorraine sequence (Beiers, 1976). This faulting has increased the fracture porosity of the shale–siltstone sequence and is the cause of numerous shows in wells drilled therein for hydrocarbons. The internal and nappe zones are characterized by relatively large-scale imbricate thrust sheets. In these zones, the potential hydrocarbon-bearing traps are the footwall structures in the Lower Paleozoic sequence beneath the surface thrust sheets.

The structure of Champlain Valley/Taconic allochthon/Green Mountain anticlinorium is similar to that of the Quebec Lowlands as shown by the COCORP New England transect, a deep seismic reflection profile across the New England Appalachians (Ando and others, 1984). On the west side of the transect, in easternmost New York, a relatively thin cover of Paleozoic rocks overlies extended Precambrian Grenville crystalline basement. To the east, in New York and western Vermont, the Taconic allochthon occurs as a subhorizontal thrust sheet, above the Champlain thrust fault, that places relatively deep-water clastic and carbonate rocks of the continental rise sequence upon the approximately time-equivalent strata of the carbonate shelf. Farther to the east in Vermont, the crystalline rocks of the Green Mountain anticlinorium occupy the upper reaches of a major tectonic ramp that extends downward, sharply to the east to a depth of 19 mi. This play, 6802, occurs to the west of the Green Mountains, where the shelf sequence is exposed along the west flank of the Adirondack Mountains and where that sequence occurs beneath shallow thrust sheets.

Reservoirs: The play occurs in the Cambrian and Ordovician sequence that occupies the footwall of the Taconic overthrust and associated thrust sheets. Potential reservoirs occur in all strata, ranging from sandstones of the Potsdam Group (Cambrian) at the base, through the predominantly carbonate strata of the Beekmantown, Chazy, and Black River Groups (Ordovician) to the shales, siltstones, and sandstones of the Utica and Lorraine Groups (Ordovician) (Guo and others, 1990, Beiers, 1970, Dykstra, 1992). It is dependent primarily on the fracture porosity that had been developed in Lower Paleozoic carbonate reservoir rock, Trenton and Black River Formations, both in the footwall and/or beneath the Taconic allochthon. In general, the oldest formations of the platform sequence are those of the Potsdam Group, which was deposited directly upon crystalline basement. The Potsdam consists of impure, feldspathic sandstones at the base that are overlain by relatively clean quartz sandstones. These are in turn overlain by the dolomites of the Beekmantown Group, calcareous sandstones and limestones of the Chazy Group, dolomites and limestones of the Black River Group, thin-bedded and shaly limestones of the Trenton Group, and up to 1200 feet of massive, calcareous black shales of the Utica Group, the probable source rock. The Utica is also a self-sourced reservoir rock, a fractured continuous-type accumulation that produces at least small amounts of gas almost everywhere it is drilled. The Utica is overlain by at least 5000 feet of shales, siltstones, and sandstones of the Lorraine Group, which is overlain in turn by red shales and sandstones of the Richmond Group (Beiers 1976).

Source rocks: Organic content of the Utica Group in the Lowland is as much as 3% and thermal maturation is suitable for the generation of gas. When drilled, shales and siltstones of the Utica and

Lorraine almost always exhibit shows of gas, and the shales are most productive where they have been extensively faulted (Beiers, 1976).

Timing and migration of hydrocarbons: Dykstra (1992) points out that thermal maturation models indicate that hydrocarbon generation in the autochthon occurred during the early phases of the Taconic orogeny and culminated with the emplacement of the thrust sheets. Traps in the autochthon and beneath the thrust sheets were charged early so that the initial porosity was preserved. In contrast, rocks in front of the thrust belt were charged later, in the Devonian, but only after much of the porosity had been destroyed diagenetically. Gas, thus, appears to occur potentially in commercial quantities in two structural settings, in the faulted and deformed shales of the Utica and Lorraine Formations in the external zone of deformation, and in subthrust areas of the internal and nappe zones.

Calculations made by log analysis of fractured Utica shales in the Quebec Lowlands (Aguilera, 1978) indicate that the formation may contain 5 BCF of gas per section (square mile, 640 acres) and that the average well would produce initially about 500 MCFPD. Cumulative production after 20 years is estimated to be about 2.5 BCFG. This estimate is based on a daily production rate of about 296 MCFPD for the average well after 20 years. Experience from other shale gas fields suggests that this decline rate is too optimistic and that the well would be producing much less, perhaps 50 MCFPD after 20 years. If so, the cumulative production estimate for the average well made by Aguilera (1978) is too high and the total resource is overestimated.

Traps: The northeastern part of the Finger Lakes region contains 11 fields that have produced gas from the Trenton and Black River Formations. Except for the structural complexities of the eastern thrust sheets, these fields occur in strata that are most likely to be potential reservoirs in the Champlain Valley/Taconic thrust sheet play and, thus, provide an analog for the potential field-size distribution in the Taconic, Champlain Valley region. These Finger Lake region fields encompass about 55 sq mi in an area of approximately 2468 sq mi or about 2.2 percent of the area. Average ultimate production per acre for these fields is 3.7 MMCFG. The potentially productive area of the Champlain Valley is about 6000 sq mi, or about 2.43 times the area of the northeast Finger Lakes region. If it is assumed that structural complexity would reduce the productive acreage to 1 percent of the area, then only 60 square miles would be productive, or about the same area as the northwest Finger Lakes region. The field sizes of the latter, thus, can be used directly in estimating the gas resources of Trenton in Champlain Valley.

Fields and production, Finger Lakes analog region, New York

Field	Ult. Prod./Acre (MMCFG)	EUR (BCFG)
Pulaski	3.3	38.0
Sandy Creek	3.3	23.2

Badwinsville	3.3	17.4
Memphis	3.3	11.6
Rome	3.3	09.0
Blue Tail Rooster	8.08	06.5 Median
Camden	3.3	04.75
Tug Hill	3.3	03.7
South Fulton	3.3	02.6
North Fulton	3.3	02.6
Clyde	3.3	00.53

Exploration status: Bayer (1988) summarized the oil and gas tests drilled into the northern part of the Champlain Valley, Vermont, none of which proved to contain commercial quantities of hydrocarbons. Since then, data from a well called the Finnegan boring that was drilled in Washington County, N. Y., were published by Guo and others (1990). The well encountered the Taconic thrust at 2764 feet, entered basement at 7440 feet and was in crystalline rocks to a TD of 7758 feet. The well contained a show of gas and oil residues.

Resource potential: Guo and others (1990) concluded that the Trenton, Black River, Chazy interval has the greatest potential for producing natural gas in this area because it contains the greatest amount of porosity and is of lower (better) thermal maturity than underlying strata. Commercial production depends, however, on the identification of fracture porosity reservoirs, perhaps deeply buried beneath Taconic thrust sheets (Ando and others, 1984). The Utica and Lorraine Formations also may produce gas in commercial quantities.

6901. EAST COAST MESOZOIC BASINS PLAY (HYPOTHETICAL)

The eastern part of the North American continent contains several dozen Mesozoic extensional basins that are distributed onshore from Florida northward to Nova Scotia, and offshore from the Blake Plateau to Georges Bank. In general, the onshore basins are situated within the Precambrian to Paleozoic rocks of the Piedmont and Blue Ridge and to a much lesser extent within Paleozoic strata along the western Piedmont margin in Maryland and southern Pennsylvania. The East Coast Mesozoic Basins Play (6901) extends from beneath the Atlantic Coastal Plain in northern Florida, Alabama, and Georgia, northeastward along the Atlantic coastal margin to southern New England. The play occurs in parts of four distinct provinces, the Piedmont, Blue Ridge, Atlantic Coastal Plain, and New England provinces, and extends eastward onto the outer continental shelf. In general, the play is bounded, in part, by the Blue Ridge Thrust Belt and Appalachian Basin Provinces (068 and 067) on the west, and by the 3-mile limit of State waters on the east. The East Coast Mesozoic Basins Play occupies an area of about 113,000 sq mi, approximately 900 miles long and 100–140 miles wide.

The East Coast Mesozoic Basins are assessed collectively as a single play that extends over parts of four provinces. Schultz (1988) described the onshore basins for the previous 1989 assessment. This present assessment is concerned with the potential undiscovered oil and gas resources of the onshore basins and of the offshore basins within the 3-mile limit. It should be noted, however, that almost all of the offshore basins are beyond the 3-mile limit.

In general, the east coast Mesozoic basins range in size from 190 sq mi or less to 190,000 sq mi or more. The exposed onshore basins, approximately 30 in number (Luttrell, 1989), occur chiefly within the Piedmont physiographic province generally from Virginia southward into the Carolinas. To the north, in Maryland and Pennsylvania, Mesozoic basins interrupt the physiographic expression of the more mountainous Blue Ridge and extend northeastward into the highlands of New England. Other basins occur widespread in the Atlantic Coastal Plain physiographic province, where they are buried beneath younger Mesozoic and Cenozoic strata at depths ranging from a few to several thousand feet (Benson 1992; Hanson, 1988, Milici and others, 1991). Parts of the South Georgia Basin extend beneath the Atlantic Coastal Plain into the Gulf Coastal Plain in northern Florida (Chowns, and Williams, 1983). Similar rift-related structures occur offshore on the Continental Shelf, where they have been imaged beneath the post-rift unconformity by regional and detailed seismic surveys. These structures include the Norfolk basin offshore of southeastern Virginia, and the Fenwick basin offshore of Delaware (for example, see Bayer, 1987 and Bayer and Milici, 1987; Benson and others, 1986, Benson, 1992).

In general, these basins formed along the continental margin in response to the regional uplift, extension, and crustal thinning that occurred during the mid-Triassic opening of the Atlantic Ocean. The basins began to form about 227 million years ago, in middle Carnian (Late Triassic) time (Manspeizer and Cousminer, 1988) along the newly formed continental margins. This Mesozoic rifting lasted for only a relatively short period of time and ended early in the Jurassic approximately concurrent with large-scale regional vulcanism, intrusion of diabase and extrusion of basalt.

Contemporaneous with rifting, the basins were filled with a variety of continental siliciclastics ranging from very-coarse boulder beds and arkosic sandstones along the basin margins, to red siltstones, mudstones, and very fine-grained gray and black lake deposits that were deposited in diverse fluvial-lacustrine environments within basin interiors. In general, the basin infilling appears to have occurred in a mountainous tropical rain forest setting of considerable local relief (see Luttrell, 1989 for a summary; Cornett and Olsen, 1990). Basins buried beneath the Atlantic Coastal Plain and on the North American Continental Shelf are separated from overlying younger deposits by a pronounced unconformity, the post-rift unconformity (Schlee and Klitgord, 1986), which marks approximately 100 million years of erosion and beveling of the pre-existing early Mesozoic topography prior to deposition of Cretaceous coastal plain sediments. This unconformity is of regional extent and has been traced throughout the seismic network that covers much of the Atlantic outer continental shelf (Klitgord, 1981).

Most of the Mesozoic basins are faulted along their western margins by east-dipping faults, and their hanging walls have moved downward relatively to the east during basin extension and filling. West-dipping faults, although not uncommon, are generally subsidiary to the eastward-dipping master set. This extensional deformation occurred coincidentally with sedimentation and basin fill, so that the first-formed deposits were deformed progressively as the basin widened. The extension, thus, not only enhanced the development of fracture porosity, especially in the older Mesozoic rocks, but also resulted in some folding of the strata within the basins and thereby formed structural traps; in places extensional deformation most certainly reduced the effectiveness of available seals.

Reservoirs: Potential reservoir rocks encompass a variety of lithologies that range from very coarse alluvial fan deposits, "fanglomerates," to fluvial and deltaic deposits that were deposited along basin margins and interfinger with adjacent finer-grained lake deposits. Because of the great amount of local relief that existed in places along faulted basin margins, deposition of these coarser-grained deposits took place very rapidly so that great thicknesses of sediments accumulated with little or no chance for reworking by the agencies of wind and water. As a result, sorting is commonly poor and the porosity between sandstone grains is commonly clogged with finer-grained siliciclastics. In contrast, deltaic and littoral sandstones that accumulated within basin interiors may constitute some of the better reservoirs, especially where they are extensionally fractured and sealed by black shale source rocks.

Conventional core analyses from 27 sandstone samples from one well in the Richmond basin, Virginia, yield values for porosity that range from 2.0% to 12.5%, with a median value of 8.2%. Permeability values for the same samples range from <0.01 to 18 mD, with a median of 0.61 mD. In the Deep River basin, North Carolina, porosities are generally low and average about 3.5% (Reid and Hoffman, in preparation). Fracture porosity may be important in some places, especially in the sedimentary strata that were deposited early in basin history.

Source rocks: The better source rocks within the Mesozoic basins are the gray and black shales that generally were deposited in lakes, offshore in deeper water environments, probably during periods of high organic productivity, and perhaps under anoxic conditions. These black shale beds may range from a few feet to several hundred feet thick. Kerogen in these beds generally consists of material derived from vascular plants and algae which, in source beds, are prone to yield both gas and oil. Thermal maturation values range widely, from within the zone of dry gas to immature with respect to liquid hydrocarbons. In the Newark and Hartford basins, thermal maturity ranges greatly over short stratigraphic distances and reflects the effects of both regional and localized high flows of heat associated with hydrothermal alteration and diabase intrusion during the final phase of basin development in the Early Jurassic (Pratt and others, 1988).

Timing and migration of hydrocarbons: A time-temperature model for the Taylorsville basin (Milici and others, 1991) indicates that the lower part of the Taylorsville basin entered the zone of oil generation about 195 Ma, in the Early Jurassic. Depending on the depth of burial and heat flow for each of the basins, hydrocarbon generation and migration into local traps appears to have been initiated concurrently with extension and sedimentation late in the Triassic and continued into the early Jurassic, when the basin extension ceased following continental breakup, separation, and the initial opening of the Atlantic Ocean.

Traps: Potential traps within the Mesozoic rift basins are likely to occur at depths ranging from about a thousand feet to almost 20,000 feet within some of the larger basins. They are likely to be formed from a combination of structural and stratigraphic features related to contemporaneous tectonic extension, basin deepening, and rapid sedimentation. Deposits in the lower parts of the basins are more likely to be complexly folded and faulted than are deposits in the upper parts of basins. Roll-over anticlines are likely to occur above listric faults along basin margins, areas that are likely to exhibit rapid lateral variations of coarse-grained siliciclastic rocks in short distances. In the Piedmont, metmorphic rocks are exposed within the perimeters of several Mesozoic basins, attesting to the complexity of local structure.

Late stage compressional structures are conspicuous features in some of the basins, to the extent that some large-scale folds exhibit a total stratigraphic thickness that exceeds present basin depths. The compressional forces that formed these larger scale folds apparently were generated as the newly formed North American continent drifted relatively eastward, away from the region of high heat flow and mantle convection that was the driving force in the disruption of the protocontinent, Pangea. Subsequently, as the continental margin cooled the recently uplifted and extended crust subsided and was compressed to fit into a lower, shorter geodesic arc, thus generating the compression that folded Mesozoic sediments within the basins.

Extensional faults of all dimensions occur within the basins and in some places may form updip cut-offs that place potential seals against coarser-grained siliciclastic reservoir rocks. Where gray to black basinal shales are suitable mature and extensively fractured, they could constitute autogenic reservoirs for the production of natural gas.

Exploration status: Although almost all of the larger basins have had some drilling in them, either for coal, oil and gas, or both, only two of them have been seriously explored for oil and gas. These are the Richmond and Taylorsville basins. Of the two, the Richmond basin appears to have been largely explored, whereas much area in the Taylorsville basin beneath the Atlantic Coastal Plain remains to be tested by the drill.

The South Georgia and associated Mesozoic basins, which lie buried beneath the Atlantic Coastal Plain, extend from Alabama and Florida through Georgia to South Carolina. They are known chiefly from several dozen wells that have penetrated the coastal plain cover. Although there is little specific data concerning these wells, three are shown by Chowns and Williams (1983) to have penetrated the Early Mesozoic section and to have entered into Paleozoic rocks identified as part of the African craton.

Four wells drilled into the Durham basin, North Carolina, exhibit multiple shows of oil and gas at depths ranging up to about 4,600 feet (Reid and Hoffman, in preparation). The shows are most commonly of natural gas and oil, with some of condensate or asphalt. Reinemund (1955) reported on the results of thirty diamond drill holes that were drilled into the Deep River Coal Field in the Durham basin between 1915 and 1950. Oil shales associated with the coal beds in these holes yield as much as 10 to 15 gallons of oil per ton and apparently could serve as source beds.

The Richmond basin, Virginia, has been drilled extensively for coal, oil, and gas. Between 1897 and 1985, 38 exploratory holes were drilled in the basin (Wilkes, 1988). Of the 38 holes, 22 were drilled to depths of 1,000 feet or more. The deepest hole, Cornell Oil Company, No. 1 Bailey, entered granite basement at 7110 feet and was drilled to a total depth of 7,438 feet. The hole encountered several coal beds, but no oil or gas. Of the remaining deep holes, 6 had shows of liquid and/or gaseous hydrocarbons. Subsequently, industry has conducted at least two core drilling campaigns for coal along the margins of the basin during the latter part of the decade. The leases apparently were abandoned because of excessive disruption of the coal beds by faulting. The extensive drilling in this relatively small basin indicates that the chances of finding significant amounts oil or gas there are minimal.

More recently, the Taylorsville Basin, Virginia, has been the subject of considerable industry interest and exploration. In 1986, Texaco, Inc. drilled 5 diamond drill core holes in the Richmond basin each to a depth of 5,500 feet, apparently the limit of the drilling rig. A sixth hole encountered crystalline basement at about 3,533 feet. The core holes were followed in 1989 by a deep test, the Texaco W. B. Wilkins et ux No. 1, which was drilled into basement at a total depth of 10,135 feet. Three of the core holes and the deep test had indications of oil and gas (Milici and others, 1991). Subsequently, Texaco drilled a second deep test in Virginia. The data for this last well, at present, remain confidential on file with the Virginia Division of Gas and Oil in Abingdon.

Three wells were drilled in York County, Pennsylvania in the early 1960's. The deepest was drilled to a depth of 8,631 feet. All were dry. A dip fence of six core holes was drilled across the Newark basin, New Jersey, in the early 1990's. The holes intersected a nearly continuous 20,000 foot-thick stratigraphic section across the lower two-thirds of the basin. The data for these wells are available from the Lamont-Doherty Geological Observatory, Palisades, N. Y. (Petzet, 1991).

Resource potential: Overall, resource potential is generally poor to fair because of relatively low porosity and permeability of potential Mesozoic sandstone reservoirs. Except for the Richmond Basin and perhaps for the Durham Basin, the play is largely undrilled. The basins with the greatest overall potential for hydrocarbon production apparently are the Taylorsville, and perhaps the South Georgia, and some of the offshore basins, such as the Norfolk Basin. Almost nothing is known of the internal stratigraphy and organic geochemistry of the latter two basins, however, and they were not evaluated in this study.

The following individual summaries are of those relatively large Mesozoic rift basins that appear to have some, if only marginal potential for generating and yielding commercial quantities of hydrocarbons.

HARTFORD BASIN

The Hartford Basin in Connecticut and Massachussetts contains approximately 18,000 feet of Upper Triassic and Lower Jurassic sediments and volcanic rocks. The lower part of the section consists of the red conglomerates, pebbly sandstones, and mudstones of the New Haven Arkose, about 14,000 ft thick. Three of the overlying Jurassic formations have at least some potential for hydrocarbon generation and production in the basin. Kotra and others (1988) sampled and studied more than 50 samples of kerogen and phytoclasts from the Shuttle Meadow, East Berlin, and Portland Formations. They determined that the kerogen is made up of material derived from mixed vascular plants and algae and is of proper maturity to have generated liquid hydrocarbons. Spiker and others (1988) concluded that the abundance of terrestrially-derived organic matter in samples they studied from the Hartford and Newark Basins favored the generation of natural gas over oil.

GETTYSBURG AND NEWARK BASINS

The Gettysburg Basin in Maryland and Pennsylvania and the Newark Basin in Pennsylvania, New Jersey, and New York contain about 22,000 to 25,000 feet of Upper Triassic and Lower Jurassic sedimentary strata and basalt flows. The flows are in the Jurassic part of the section and their intrusion was associated with a relatively brief period of unusually high heat flow in the basins. The two basins are connected by a more or less deformed "narrow neck" of Triassic conglomerates, sandstones , and red beds. The Gettysburg Basin to the south contains relatively few gray shale source beds, although Ziegler (1983) reports that the Leib no. 1 Sheppard well ran production casing in 1962 and produced 2.5 BO. Most of the stratigraphic sequence consists of thousands of feet of red sandstone, shale, conglomerate, and arkose with subsidiary red, green, and gray shale. In the Newark basin several formations, including the Jurassic Towaco and Feltville Formations and the Triassic Passaic and Locatong Formations, contain gray or black lacustrine beds which have some source rock potential.

According to Katz and others (1988), organic geochemical data indicate that there is only a limited potential for hydrocarbon production in the basin. The Triassic part of the section generated hydrocarbons early in the history of the basin, but generation apparently ceased when the basin was uplifted and eroded. The Jurassic part of the section is generally immature with respect to hydrocarbon generation because of relatively shallow depths of burial. Pratt and others (1988) noted that overmature Triassic strata are overlain by mature and immature Jurassic strata over a narrow stratigraphic interval. They attributed this telescoping of geothermal maturation zones to a pulse of high heat flow that occurred early in the Jurassic simultaneously with the emplacement of basalt flows on younger strata.

The uneven distribution of source beds and the rapid variation of their thermal maturity levels in short distances, when coupled with relatively low intergranular porosity and permeability of potential sandstone reservoirs, makes exploration for hydrocarbons in these basins speculative at best.

CULPEPER BASIN

The Culpeper Basin, Virginia contains a thick sequence of Upper Triassic to Lower Jurassic non-marine sedimentary rocks with an aggregate thickness of about 18,000 feet. The sequence is divided into seven sedimentary formations that contain two named basalt formations. Of the former, the Midland Formation and Balls Bluff Siltstone contain dark-gray lacustrine shales that may have some potential as a petroleum or natural gas source rock (Lee and Froelich, 1989). Smith and Robison (1988) followed Lindholm's (1979) stratigraphy and determined that lacustrine deposits in Lindholm's (1979) Bull Run Formation, an equivalent of the Balls Bluff Formation of Lee and Froelich (1989), are overmature with respect to the liquid hydrocarbon window (mean R_o = 1.69 percent), with some R_o values greater than 2.00 percent and are indicative of the dry gas zone. In addition, their whole-rock pyrolysis data for the Bull Run Formation indicate that its kerogen is gas-prone type III which has been highly degraded. In contrast, samples collected by Smith and Robison (1988) at the Midland fish bed of the Midland Formation indicate that these strata are a source rock that has potential for oil generation. Kerogen types are dominantly type I and II, with lesser amounts of type III. Black shales within the Waterfall Formation at the top of the Mesozoic section in the Culpeper Basin contain sufficient amounts of organic matter to be source rocks, but are relatively immature with regard to oil generation. Kerogen is a mixture of types I and II, so that the oil-prone organic matter is at a very early stage of oil generation.

RICHMOND BASIN

Coal was mined from the Richmond Basin by Huguenot settlers and used locally by 1703. The coal mines proved to be excessively gassy and as a result many miners were killed by explosions in subsequent years (Wilkes, 1988). The basin has been extensively drilled both for coal, oil, and gas. Much of the coal test information that was developed by industry during the 1980's remains proprietary. Wilkes (1988), however, has documented 22 oil and gas or coal tests that were drilled to depths of 1000 feet or more into Richmond Basin rocks. Of these, 6 reported shows of oil but nothing was discovered in commercial quantities. The deepest well, the Cornell Oil Company, Bailey No. 1, was drilled in 1981 and encountered basement at a depth of 7110 ft (Wilkes, 1988).

The most likely source beds for oil in the Richmond basin are the lacustrine gray to black shales within the Upper Triassic Vinita Beds. The Vinita Beds are about 6000 ft thick and consist of strata that were deposited in fluvial and deltaic environments around the margins of the basin and in lacustrine environments in the basin center (Goodwin and others, 1985). Robbins and others (1988), from a study of coal beds and pollen and spore colors from rocks in the Richmond Basin and the Deep Run Basin nearby, have documented that thermal maturation ranges from submature to supermature with respect to oil generation.

TAYLORSVILLE BASIN

The Taylorsville Basin, which lies almost entirely buried beneath the Atlantic Coastal Plain, has attracted considerable interest by industry during the past several years. The exposed part of the basin has been mapped and described in detail by Weems (1980, 1981, 1986) and Goodwin and others (1985). The deeper parts of the basin were explored by three oil and gas tests and by six diamond drill holes cored by Texaco, Inc. Texaco's first oil and gas test, in 1989, was drilled to basement at a depth of 10,135 ft. Data from all but the last oil and gas test, as well as an interpretation of a regional vibroseis line across the basin, are presented by Milici and others (1991). Three of the core holes as well as the Texaco Wilkens et ux no. 1 oil and gas test exhibited shows of hydrocarbons, although not in commercial quantities. Palynomorphs from the exposed part of the basin have yielded TAI colors that indicate these strata are within the thermal zone of oil generation (see Milici and others, 1991 for a summary). Proprietary data from the Wilkins well indicates that there are about 200 feet of gray shale in the lower half of the well that are potentially suitable for source beds.

DAN RIVER–DANVILLE BASIN.

The Dan River–Danville Basin is a relatively narrow, elongate basin that extends for a distance of about 110 mi from within the south-central Virginia Piedmont into adjacent North Carolina. In general, the basin is not highly regarded as a possible source for oil and gas. Potential source beds are overmature with respect to oil generation and potential reservoir sandstones are poorly sorted and have low porosity and permeability (Olsen and others, 1991). This conclusion is supported by analyses of five coal samples presented by Robbins and others (1988), which range in rank from semianthracite to anthracite. Stratigraphic data presented by Myertons (1963), and geochemical data presented by Reid and Hoffman (in preparation), however, indicate that there may be some potential for natural gas production from the basin. The potential source bed is the Cow Branch Formation, which consists of about 9500 ft of black to dark-gray lacustrine claystone, shale, siltstone, and some sandstone. Twelve analyses, averaging TOC

3.42 percent, from one well in the Cow Branch Formation exceed minimum values required for hydrocarbon generation and expulsion (Reid and Hoffman, in preparation). Limited hydrogen/carbon and oxygen/carbon data indicate that kerogen in the Dan River Basin is type III, so that the source rocks would be gas prone; vitrinite reflection data indicate that thermal maturation ranges from about the lower limit of the thermal zone of oil generation into the upper limits of the zone of dry gas generation. It can be concluded that, if hydrocarbons are found in commercial quantities, they most likely would be gas and would be produced from fracture-enhanced reservoirs.

DEEP RIVER BASIN

The Cumnock Formation in the Deep River Basin is an excellent source for hydrocarbons. It is a low grade oil shale about 700 to 800 ft thick and in places contains one or two coal beds (Reinemund, 1955; Reid and Hoffman, in preparation). TOC of the Sanford Formation averages 5.17 percent, organic matter is generally type III, and available vitrinite reflectance data indicate a range of hydrocarbon generation potential from oil and peak wet-gas generation to dry gas generation (Reid and Hoffman, in preparation). TAI indices from three samples of palynomorphs in the Deep River Basin and the rank of 11 samples of coal indicate that thermal maturation levels are mature with respect to oil generation (Robbins and others, 1988). As in the Dan River–Danville Basin, porosities in the Deep River Basin are very low and average about 3.5 percent. Production of hydrocarbons from the Deep River Basin, thus, most likely would be natural gas from fractured reservoirs.

UNCONVENTIONAL PLAYS

There are no unconventional plays described in this province report. However, unconventional plays listed in the surrounding provinces may include parts of this province. Individual unconventional plays are usually discussed under the province in which the play is principally located.

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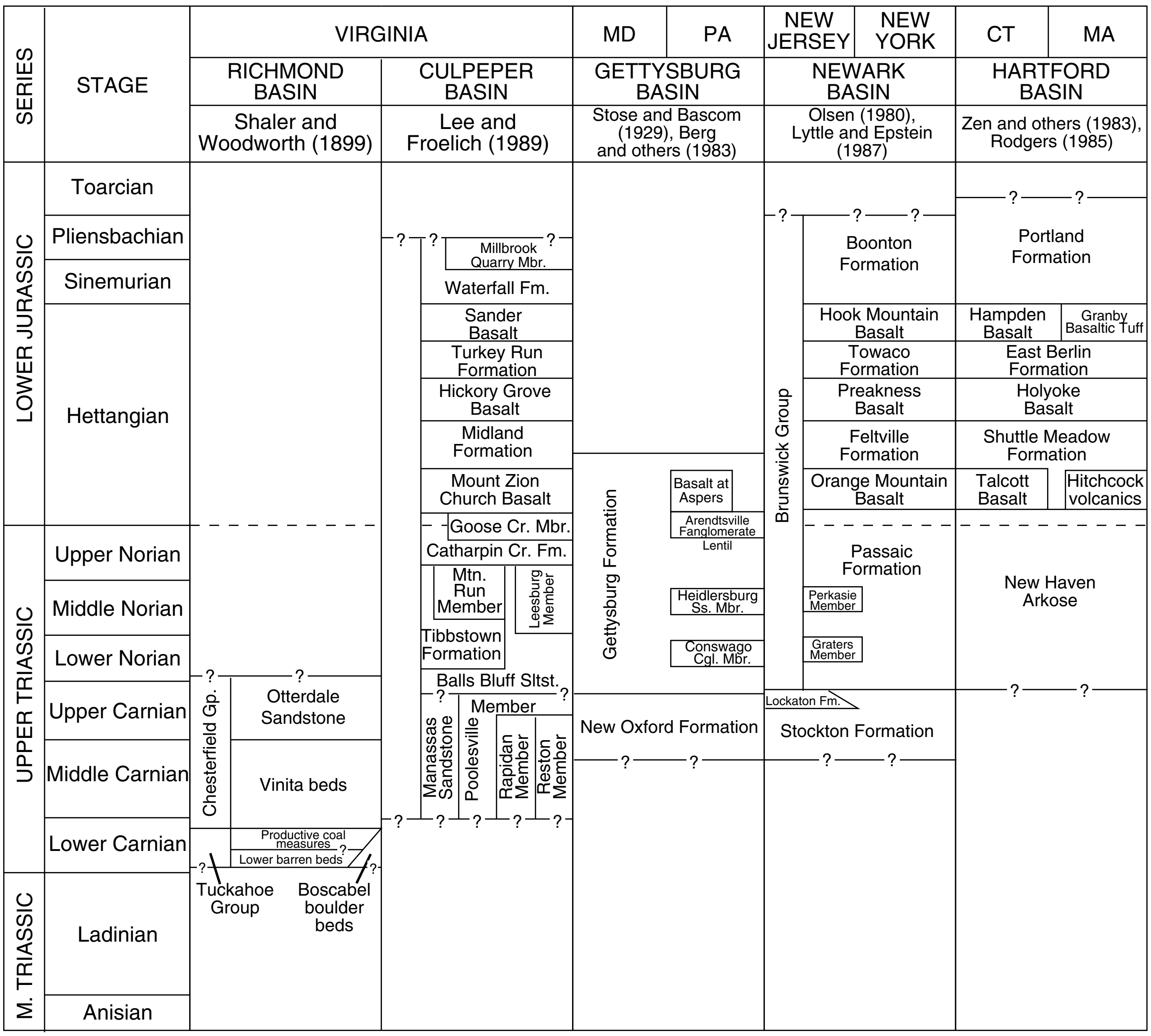
SERIES
STAGE
VIRGINIA
MD
PA
NEW JERSEY
NEW YORK
CT
MA
RICHMOND BASIN
CULPEPER BASIN
GETTYSBURG BASIN
NEWARK BASIN
HARTFORD BASIN
Shaler and Woodworth (1899)
Lee and Froelich (1989)
Stose and Bascom (1929), Berg and others (1983)
Olsen (1980), Lyttle and Epstein (1987)
Zen and others (1983), Rodgers (1985)
LOWER JURASSIC
UPPER TRIASSIC
M. TRIASSIC
Toarcian
Pliensbachian
Sinemurian
Hettangian
Upper Norian
Middle Norian
Lower Norian
Upper Carnian
Middle Carnian
Lower Carnian
Ladinian
Anisian
Chesterfield Gp.
Otterdale Sandstone
Vinita beds
Productive coal measures
Lower barren beds
Tuckahoe Group
Boscabel boulder beds
Millbrook Quarry Mbr.
Waterfall Fm.
Sander Basalt
Turkey Run Formation
Hickory Grove Basalt
Midland Formation
Mount Zion Church Basalt
Goose Cr. Mbr.
Catharpin Cr. Fm.
Mtn. Run Member
Leesburg Member
Tibbstown Formation
Balls Bluff Sltst.
Member
Manassas Sandstone
Poolesville
Rapidan Member
Reston Member
Gettysburg Formation
Basalt at Aspers
Arendtsville Fanglomerate Lentil
Heidlersburg Ss. Mbr.
Conswago Cgl. Mbr.
New Oxford Formation
Brunswick Group
Boonton Formation
Hook Mountain Basalt
Towaco Formation
Preakness Basalt
Feltville Formation
Orange Mountain Basalt
Passaic Formation
Perkasie Member
Graters Member
Lockaton Fm.
Stockton Formation
Portland Formation
Hampden Basalt
Granby Basaltic Tuff
East Berlin Formation
Holyoke Basalt
Shuttle Meadow Formation
Talcott Basalt
Hitchcock volcanics
New Haven Arkose