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The Middle and Upper Ordovician Bioclastic Carbonate ("Trenton") Play in the Appalachian Basin

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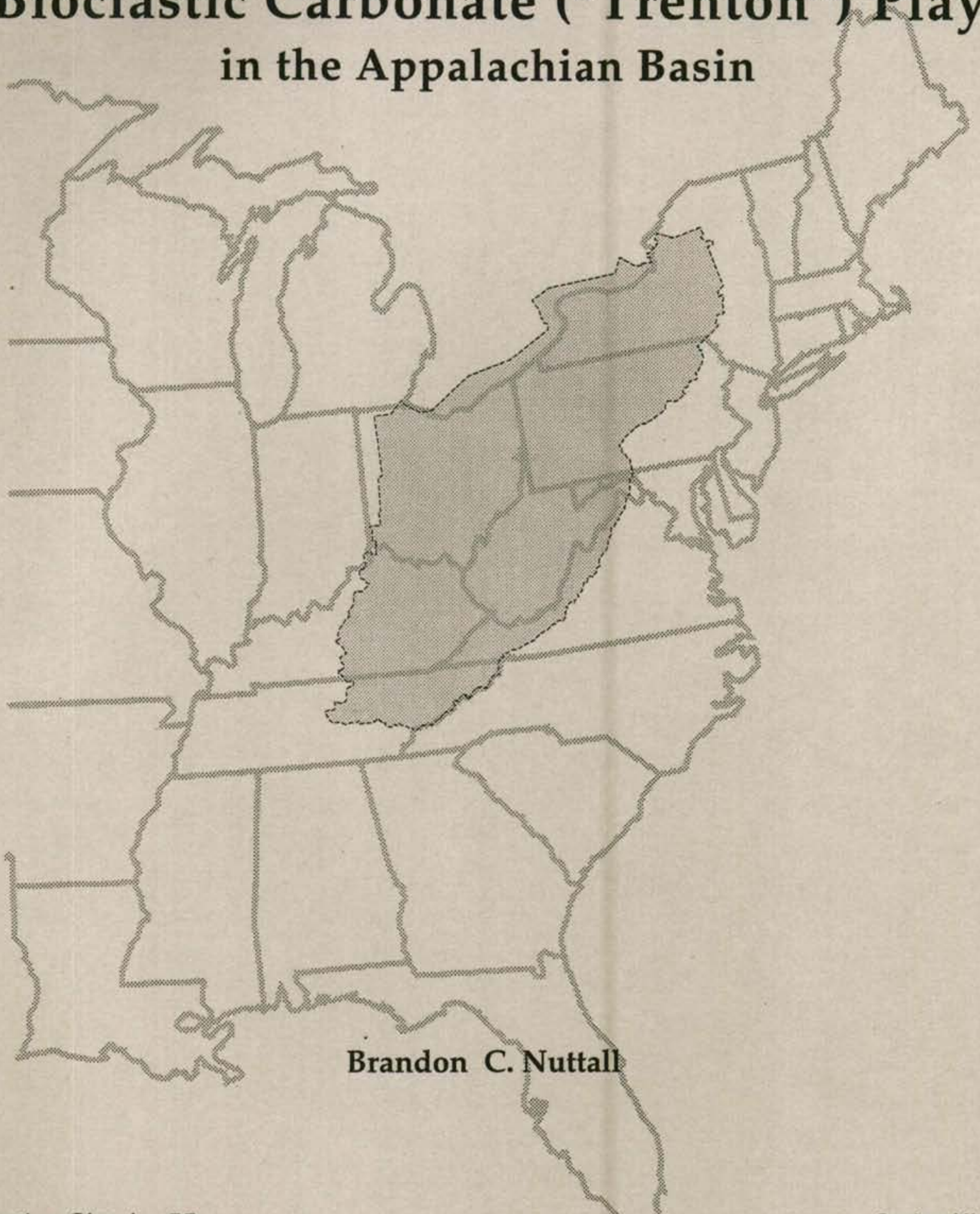

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ABSTRACT

The bioclastic carbonate play in the Appalachian Basin (referred to by drillers as the "Trenton") includes both gas and oil produced from Middle and Upper Ordovician stratigraphic and combination traps in linear reservoirs often mistaken for reefs. While production from this play is currently reported from nine fields in south-central and eastern Kentucky and five fields in New York, potential reservoir rocks are present throughout most of the Appalachian Basin from New York to Tennessee. Along the western flank of the Appalachian Basin, in the Blue Grass Region of central Kentucky, Middle and Upper Ordovician strata crop out. In the subsurface of south-central Kentucky and eastward into the Appalachian Basin, drillers informally refer to "Trenton," "Sunnybrook," "Leipers," "Granville," "Modoc," and "Anderson" pay zones. The mixed carbonates and shales of the Lexington Limestone through the Drakes Formation of Kentucky consist of well-cemented bioclastic grainstones and mudstones separated by relatively thin calcareous shales deposited in shallow platform, ramp, and peritidal settings. In areas of shoaling, reservoirs developed as discontinuous coquinoid lag deposits that were winnowed from carbonate muds by wave and tidal activity and accumulated as discrete offshore bars, tidal bars, and channel fills. In addition, dolomitized limestone reservoirs have developed along faults and fractures associated with recurrent movement of deep-seated basement faults. Structure mapping on the base of the overlying Devonian shale and the underlying Pencil Cave bentonite indicates the bars and channel fills may be spatially associated with basement structures. The Granville Consolidated Pool in Clinton County, Ky., is typical of fields in this play where production is associated with multiple stacked sequences of offshore bars. An estimated 50 to 100 million cubic feet (MMcf) of gas per year is known to be produced from this field, not accounting for production from an unknown number of domestic supply wells. Monte Carlo simulation was used to estimate the undiscovered recoverable resource for this play to be 127 billion cubic feet (bcf) of natural gas. These reservoirs will probably not be an important *primary* target for future drilling outside of southern and eastern Kentucky, however, because the reservoirs are relatively deep throughout much of the basin and are subtle stratigraphic features that will be difficult to detect using seismic or remote-sensing methods. As exploration and development continues for Lower Ordovician and Upper Cambrian reservoirs, these bioclastic carbonate bars will merit further evaluation.

DEFINITION

A play consists of geologically similar prospects that share the same source, reservoir, and trap controls, as well as common elements of risk. A play's name is based on its geologic age, formation name, reservoir facies, or trap type.

LOCATION

The Middle and Upper Ordovician bioclastic carbonate ("Trenton") play includes both gas and oil produced from stratigraphic and combination traps formed by Ordovician bioclastic carbonate bars (Sullivan and Pryor, 1988) and from secondary porosity developed in linear dolomitized zones (Black, 1986). Middle and Upper Ordovician carbonates of Shermanian (late Champlainian) and Cincinnatian age are present throughout the subsurface of the Appalachian Basin. Production from this play is currently reported from nine fields in eastern Kentucky and five fields in central New York (Fig. 1). Probable productive limits of the play are shown on Figure 1 and are based on the distribution of argillaceous and clean carbonate facies of Shermanian age shown in Keith (1988). The estimated total potential area of the play is 72.7 million acres. Within this area, there are 23.7 million acres, primarily in Kentucky, where clean carbonates of Cincinnatian age are present in addition to the Shermanian facies. In addition, this play ex-

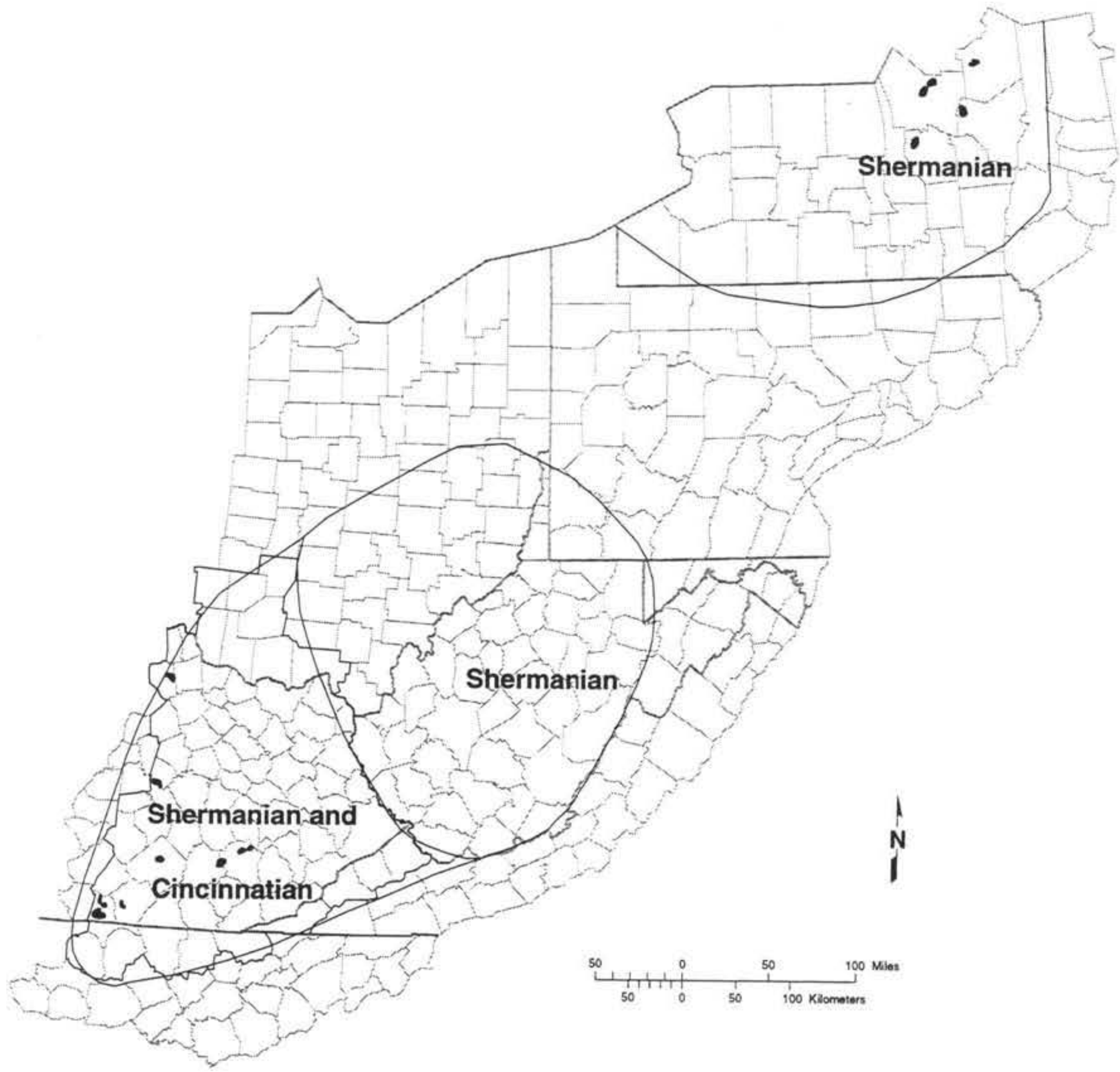

Figure 1. Location of the Upper Ordovician bioclastic carbonate (Trenton) limestone play within the Appalachian Basin, showing existing pools and the distribution of shallow-shelf, clean carbonate facies.

tends across the Cumberland Saddle in southern Kentucky to the eastern flank of the Illinois Basin. Appendix A gives basic data for fields included in this play.

PRODUCTION HISTORY

In 1829, oil was discovered in Upper Ordovician rocks of Kentucky with the drilling of the Great American well on the Stockton lease in Cumberland County. By the 1860's, several companies had been formed to explore southern Kentucky for oil and brines. This activity spread eastward across the Cincinnati Arch onto the flanks and core of the Appalachian Basin. The earliest drilling activity in the bioclastic carbonates for which a record exists is summarized by Diamond (1943) and Jillson (1946). The Granville Consolidated Pool, in Clinton County, Ky. (Fig. 2), was discovered in 1861 with the drilling of the Old Matilda Gabbard well to a depth of 264 feet. This well encountered an unnamed pay near the base of the Cincinnatian Series (Jillson, 1946). Its producing zone was later named "Granville" (Fig. 3) when the Big Rock Oil Company completed several successful wells on the Granville Williams lease in Clinton County (Diamond, 1943). Drilling also began in New York in the late 1800's in response to reports of the discovery of oil in the Trenton Limestone near Lima, Ohio (Art Van Tyne, oral commun., 1994); gas was discovered in the Trenton around the southwestern flank of the Adirondack Mountains east of Lake Ontario (Fig. 1). Heck (1948) reported that this gas is produced from dark-gray limestones interbedded with thin beds of black or dark-gray shale. Upper Ordovician shale and Middle Ordovician Trenton Limestone have been penetrated by drilling in Ohio and West Virginia. Carter and others

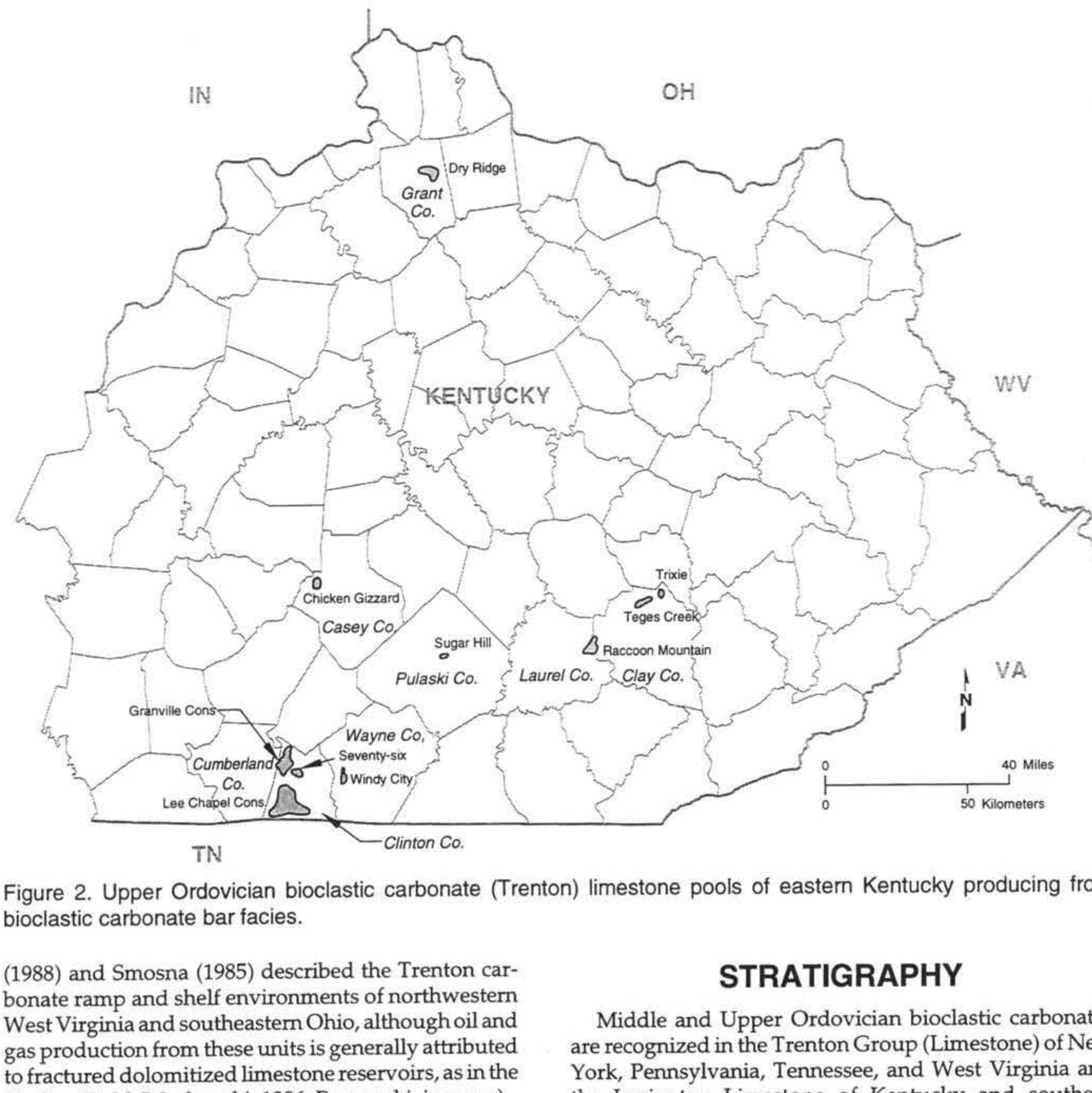

Figure 2. Upper Ordovician bioclastic carbonate (Trenton) limestone pools of eastern Kentucky producing from bioclastic carbonate bar facies.

(1988) and Smosna (1985) described the Trenton carbonate ramp and shelf environments of northwestern West Virginia and southeastern Ohio, although oil and gas production from these units is generally attributed to fractured dolomitized limestone reservoirs, as in the Harlem Field (Maslowski, 1986; Baranoski, in press).

Cumulative production data for this play are generally not available. Sparse data available (New York Division of Mineral Resources, 1987; Van Tyne, oral commun., 1994) indicate more than 2 bcf of gas have been produced from the Pulaski and Sandy Creek Fields of New York. Most of the gas wells producing from Middle and Upper Ordovician strata in Kentucky are completed for single residential or agricultural domestic gas, for which no production data exist.

STRATIGRAPHY

Middle and Upper Ordovician bioclastic carbonates are recognized in the Trenton Group (Limestone) of New York, Pennsylvania, Tennessee, and West Virginia and the Lexington Limestone of Kentucky and southern Ohio. Bioclastic carbonate bars are also present in various formations within the Cincinnatian Series in Kentucky and southern Ohio. Figure 3 is a generalized correlation chart modified from Harper (1979), Patchen and others (1985a-b), Shaver (1985), and Keith (1988) that shows the variations in Middle and Upper Ordovician nomenclature from Tennessee to New York. Commonly, the oil and gas producing zones in these strata are very local in extent and thus are assigned informal drillers' names like Granville. In general, the Middle and Upper Ordovician bioclastic carbonate sequence is disconformably underlain by massive Blackriveran-age carbonates and unconformably overlain by Upper Ordovician or Lower

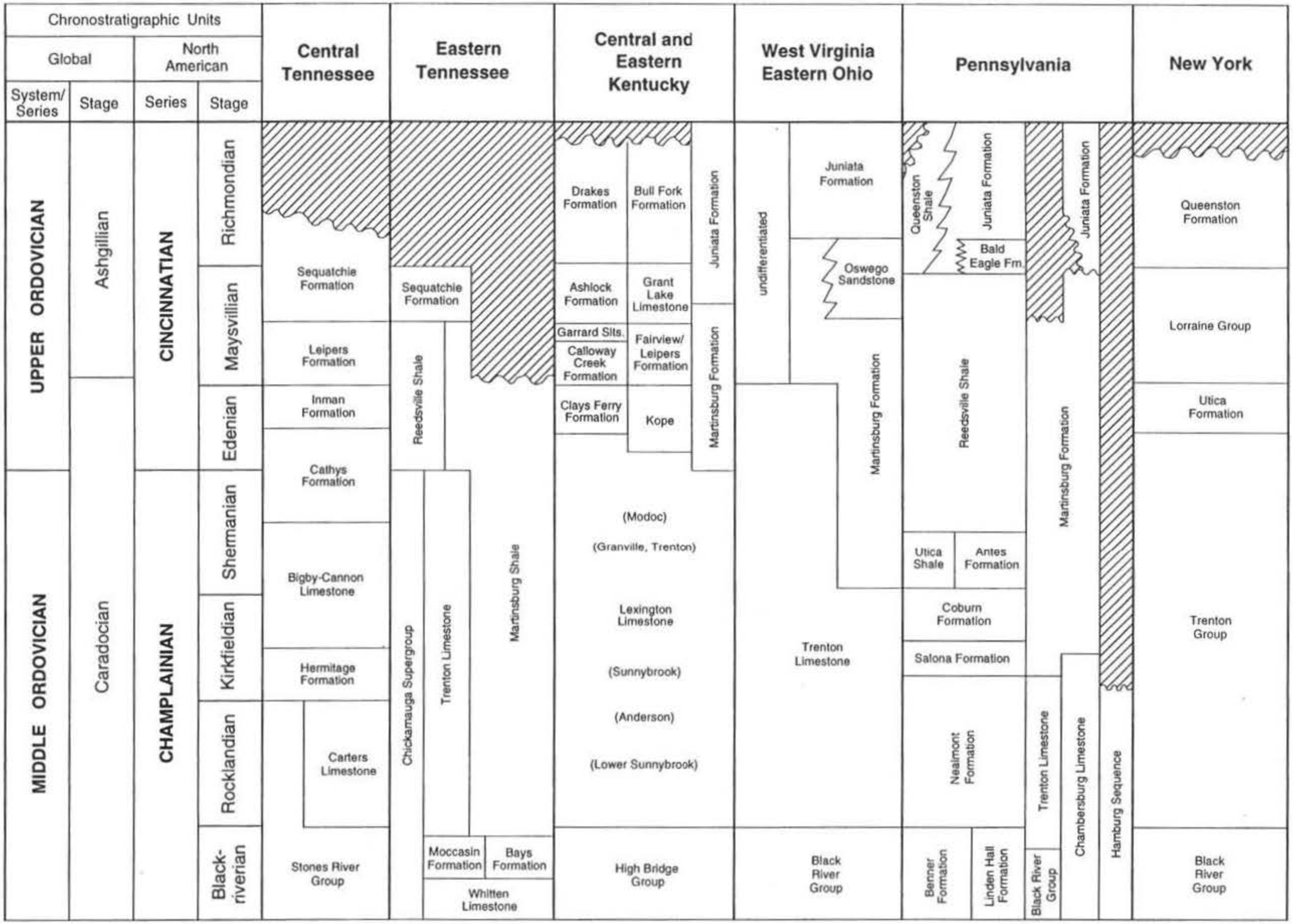

Figure 3. Generalized stratigraphy of the Upper Ordovician in the Appalachian Basin showing regional equivalents and correlations. Modified from Patchen and others (1985a–b), Shaver (1985), and Keith (1988). Drillers' terms shown in parentheses.

Silurian clastic sequences. Facies changes and depositional environments of the Middle and Upper Ordovician sequence in Kentucky are summarized by Freeman (1953), Cressman (1973), Cressman and Noger (1976), and Weir and others (1984) and regional changes are summarized by Keith (1988).

A broad, relatively shallow carbonate shelf existed throughout most of the Appalachian Basin at the close of Blackriverian time. This carbonate shelf continued into Champlainian and early Cincinnatian time, but received periodic influxes of shales, siltstones, and sandstones from the northeast (Fig. 3). The clastics interrupted carbonate deposition and resulted in argillaceous carbonates and alternating carbonates and shales over much of the western and southern extent of the platform. These mixed carbonates and shales typically consist of well-cemented bioclastic grainstones and carbonate mudstones separated by relatively thin calcareous shales that developed in shallow-platform and peritidal settings. In high-energy, shallow shelf environments such as shoals and beaches, discontinuous coquinoid lag deposits were winnowed from carbonate muds by wave and tidal activity and accumulated as discrete offshore bars, tidal bars, and channel fills (Sullivan and Pryor, 1988). A generalized depositional model (Fig. 4) based on studies by Ginsburg (1975), Wilson (1975), and Walker and James (1992) shows the distribution of a variety of carbonate shelf facies that characterize parts of the Middle and Upper Ordovician sequence in the play area. A type log for part of the Middle and Upper Ordovician of Kentucky (Fig. 5) shows the Granville in a representative stratigraphic position for reservoirs in this play.

The Cincinnatian Series in Kentucky and southern Ohio consists of interbedded carbonate and clastic lithologies of the Fairview, Leipers, Ashlock, Drakes, Grant Lake, and Bull Fork formations that often contain the bioclastic carbonates associated with this play. Weir and others (1984) summarized the stratigraphy, facies, depositional environments, and paleogeography of the Cincinnatian Series. Figure 6, a generalized facies map of Cincinnatian time, shows the distribution of carbonate and clastic rocks for the eastern United States. The limestone units represent deposition on a broad, mostly open-marine, shallow to moderate-depth carbonate shelf with local intertidal and supratidal flats. Clastic sediment influx from deltaic and alluvial plains to the northeast modified and sometimes interrupted carbonate deposition. Discontinuous deposits of medium- to coarse-grained calcarenites, often characterized by low-angle crossbedding (as in lithofacies H of Weir and others, 1984), occur throughout the Cincinnatian section; examples include the Leipers Formation of southern Kentucky and Tennessee and the Grant Lake and Drakes Formations of northern and northeastern Kentucky.

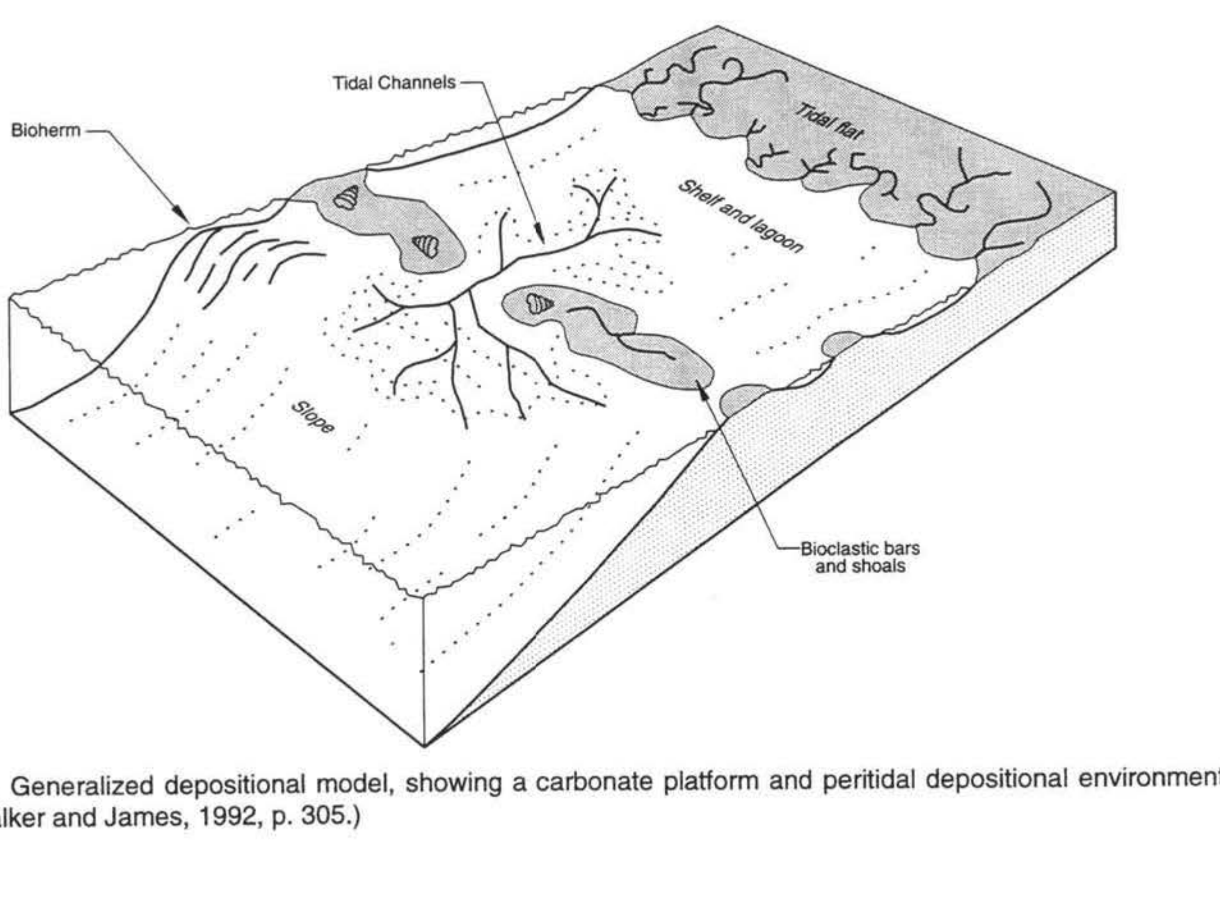

Figure 4. Generalized depositional model, showing a carbonate platform and peritidal depositional environments (after Walker and James, 1992, p. 305.)

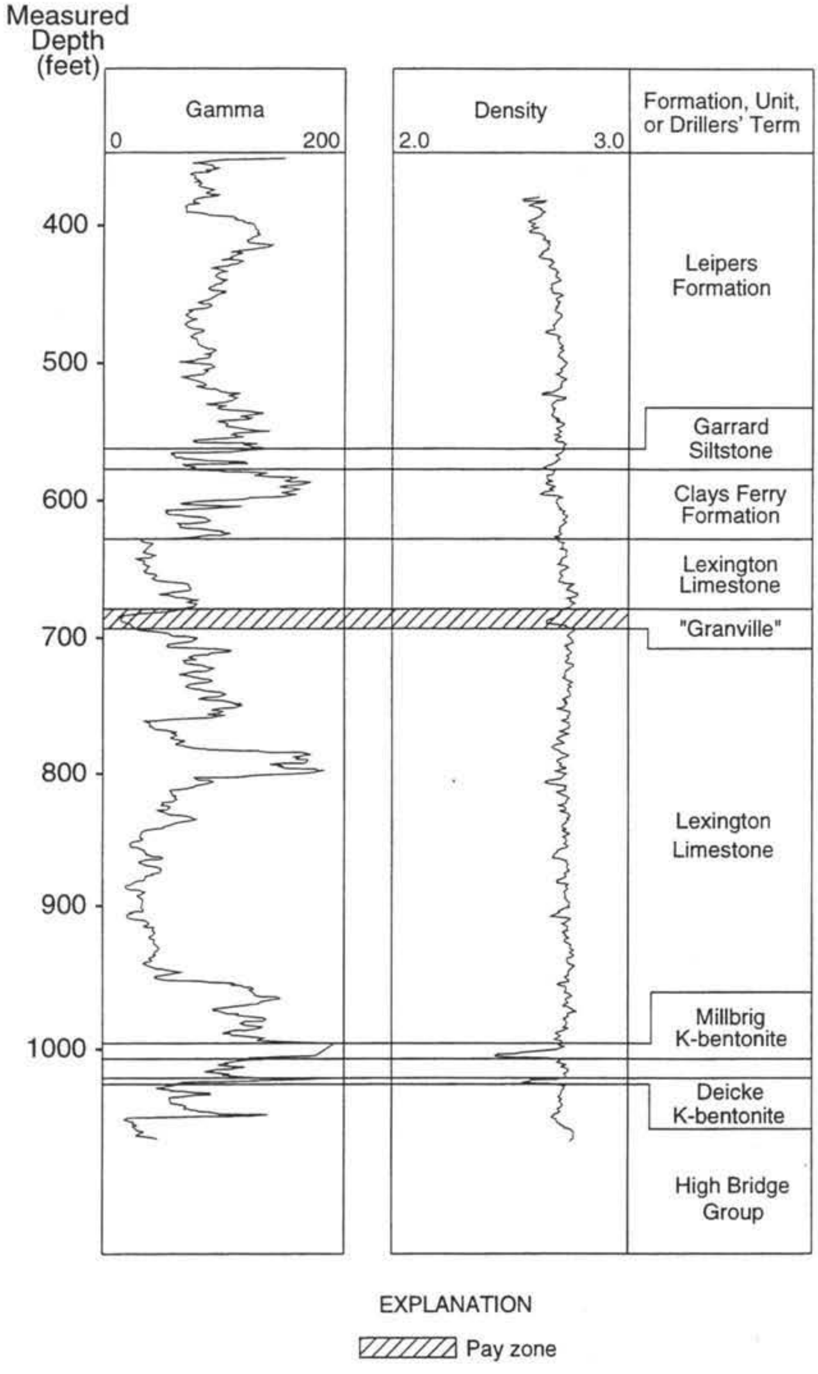

Figure 5. Upper Ordovician bioclastic carbonate (Trenton) type log.

The Clays Ferry Limestone of northern Kentucky and adjoining Ohio conformably overlies and intertongues with the Lexington Limestone and consists of interbedded thin shales, limestones, and siltstones (Weir and Greene, 1965). It grades upward into the Garrard Siltstone. The Clays Ferry Limestone and Garrard Siltstone units are not part of the bioclastic carbonate play, but the Garrard Siltstone may be productive and has been mistaken in the subsurface for the Granville, a producing zone in the Lexington Limestone (Wilson and Sutton, 1973).

The Lexington Limestone is a heterogeneous lithologic sequence of dominantly bioclastic, fossiliferous, tabular, gray limestones commonly interbedded with shale that exhibit crossbeds, flow rolls, and other current-related and tidally influenced features (Black and others, 1965). It is correlative with the Trenton Limestone and Trenton Group of Tennessee, West Virginia, Ohio, Pennsylvania, and New York. The Lexington Limestone is often referred to by drillers as the Trenton or Sunnybrook. Pay zones are informally referred to as Granville, Modoc, Anderson, and Lower Sunnybrook. Stacked occurrences of the bioclastic lithology in the Lexington Limestone are often the First or Second Granville. Cressman (1973) summarized the stratigraphy of the Lexington Limestone and described several facies within the Lexington Limestone characterized in part by calcarenites and bioclastic coquinas. Intertidal calcarenites in the Lexington Limestone with prominent crossbedding are discussed by Hrabar and others (1971). Figure 7 shows the generalized facies distribution for the Shermanian Series in the eastern United States, the time when the upper part of the Lexington Limestone was deposited. Areas of shoaling indicated by clean carbonate rocks are shown in south-central, southeastern, and northern Kentucky (Fig. 7). The Lexington Limestone disconformably overlies the High Bridge Group and is exposed throughout much of the central Blue Grass Region of Kentucky.

The High Bridge Group in Kentucky, consisting mainly of massive limestone and dolomite, underlies the bioclastic carbonates of the play. A lithographic limestone developed at the top of the High Bridge Group marks the close of the Middle Ordovician Blackriveran Stage in Kentucky. As described by Cressman and Noger (1976), the finely laminated micrite and dolomite with mud cracks and birdseye calcite in the High Bridge Group are indicative of dominantly intertidal and supratidal environments. The Millbrig (Mud Cave) and Deicke (Pencil Cave) bentonites, near the top

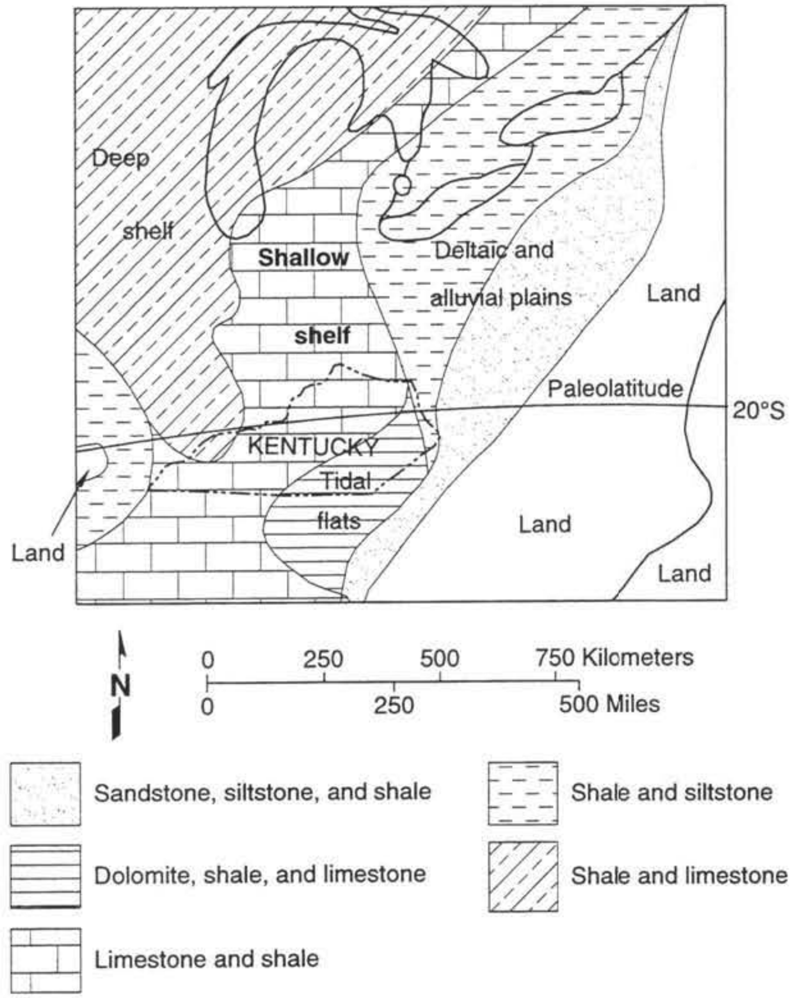

Figure 6. Facies distribution of central and northern Appalachian Basin area during Late Cincinnatian time (Weir and others, 1984).

of the High Bridge Group (Fig. 5), have been identified and correlated from the Mississippi Valley to the Appalachians (Huff and Kolata, 1990) and are utilized as chronostratigraphic marker beds during drilling and for subsurface mapping. When nuclear logs are available and used for correlation, the Millbrig bentonite is assumed to be the top of the High Bridge Group.

Trenton Limestone samples from a well drilled in the Sandy Creek Field, northwestern Oswego County, N.Y., indicate that some of the main gas-producing zones in the area are highly fossiliferous or "shelly" limestone in the otherwise massive Trenton Limestone (Art Van Tyne, oral commun., 1994). The gas in the Trenton Limestone fields of New York is trapped in interskeletal porosity of the bioclastic limestones and sealed by the surrounding impermeable limestone. Van Tyne (oral commun., 1994) suggested that there may have been an arc of shoaling in the onlapping Trenton Limestone around the southern flank of the Adirondacks, where biostromal or coquinitic beds were deposited.

STRUCTURE

Subtle geologic structures of the western margin of the Appalachian Basin and the Cumberland Saddle of central Kentucky have an important role in the location of the fields of this play. Many of the fields are associated with nosing and flexures on structure-contour maps of the Ordovician Pencil Cave bentonite and the top of the Devonian Chattanooga Shale (Fig. 8). Diamond (1943) noted production along a north-south structure, the Ill-Will Anticline, in Clinton County, Ky. (a part of which is shown on Figure 8). Moreover, Jillson (1946) showed that 12 oil or gas pools productive from the Granville or shallower bioclastic carbonate reservoirs are aligned along this structure. Jillson (1946, p. 23) stated that the rocks of Clinton County dip generally southeast and northwest and "constitute a ... monocline ... [that] is locally flexed." Figure 8 shows the structure on the top of the Chattanooga Shale in Clinton County, and the alignment of the Granville Consolidated Field along positive structural features (Thomas and others, 1950). Many of these subtle structural features are not apparent on regional maps (Potter, 1978).

Alternatively, Black (1986) has proposed that some of the oil and gas traps in Kentucky could be expected to occur in narrow, linear, dolomitized zones along normal and strike-slip faults associated with interpreted basement faults in the region. He suggested the Albion-Scipio trend in Michigan as a model for these fault-related dolomitized reservoirs, and demonstrated the occurrence of linear oil and gas fields along the flanks of aeromagnetic highs in Kentucky. He concluded that the dolomitized traps occur as grabens or half-grabens, and that traps probably occur in other parts of eastern Kentucky (see Baranoski, in press).

According to Van Tyne (oral commun., 1995) the relationship of structure to Trenton production in New York has not been investigated. Some production is believed to be related to fracturing caused by various post-depositional tectonics. The Trenton fields of New York associated with this play are bioclastic accumulations with little or no structural components controlling the reservoirs.

RESERVOIR

Kentucky statutes require production data, currently reported to the Kentucky Revenue Cabinet, to be held confidential. Therefore, reservoir data for this play were

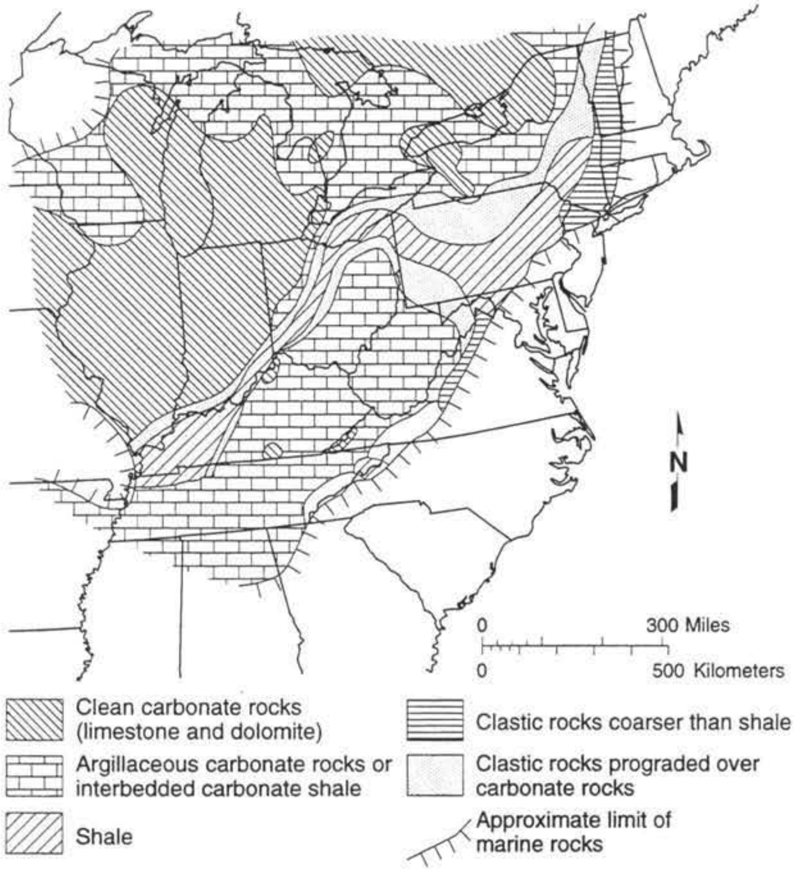

Figure 7. Facies distribution of eastern North America during Shermanian (Lexington/Trenton) time, according to data derived from COSUNA charts by Keith (1988).

mainly derived from drillers' logs, geophysical logs, and accounts of production from the literature.

According to Sullivan (1983), stratigraphic traps of the Upper Ordovician Granville zone are sealed by fine-grained, impermeable strata and tightly cemented grainstones. The primary source of the hydrocarbons in this play is the organic-rich Mississippian-Devonian black-shale sequence. An additional local source may be the very dark-gray dolomudstones and shales of the Lexington Limestone, which have a total organic content (TOC) of up to 2 percent (Sullivan, 1983). Major migration avenues for hydrocarbons derived from the Devonian shales in the basin are provided by faults, fractures, and the Ordovician Knox paleokarst system. In Kentucky, where the Middle and Upper Ordovician sequence is a common drilling target, depths to the pay range from less than 200 feet along the crest of the Cincinnati Arch to more than 2,000 feet farther east into the Appalachian basin. Where the Middle and Upper Ordovician sequence is deeper than 2,000 feet, the bioclastic reservoirs of this play are not usually a primary drilling target. Net pay thickness averages 10 feet, whereas the average completion interval is 15 to 20 feet. According to Jillson (1946, p. 30), the "thickness of oil saturation ranges from 5 to 25 feet; usually 7 to 15 feet. The oil in the Granville is accompanied by gas, frequently in considerable volume."

In the early history of oil and gas development, wells were drilled with cable-tool rigs. According to Jillson (1946, p. 17), when a well encountered gas it was allowed to "blow itself out" in the hope of bringing on commercial amounts of oil, even though this practice was detrimental to the ultimate recovery of oil in the field. Unfortunately, reservoir pressure data are not available for the fields in this play. In current practice, wells are air-rotary drilled and typically completed in the open-hole below 7-inch casing. If stimulation is deemed necessary, most wells are acidized in the open hole.

Average initial open flows, after stimulation, for various fields in the play range between 8 and 500 thousand cubic feet of gas per day (Mcfgpd), with many less than 100 Mcfgpd. The overall average reported flow (n=7) is 368 Mcfgpd, and the median flow is 45 Mcfgpd. The maximum flow recorded was 7.5 million cubic feet of gas per day (MMcfgpd) from the Tennessee Land and Exploration Company No. 1 Gilbert Bishop and others, Carter coordinate section 6-J-71, in the Trixie Consolidated Field, Clay County, Ky. The low matrix porosity of the reservoir suggests that production may have been enhanced by fracture permeability, however. The drive mechanism for these Middle and Upper Ordovician bioclastic reservoirs is interpreted to be gas expansion.

Reservoir porosity was calculated from logs available in four fields and from one core analysis. Average matrix porosity for all five fields is 11.8 percent and the maximum porosity is 15 percent. The dominant porosity types are moldic, interparticulate, intraparticulate, and intercrystalline. The core from the Jarvis No. 2 Dickens well, Granville Consolidated Pool, Clinton County, indicates an average reservoir permeability of 57.1 millidarcies (md) and a maximum permeability of 293 md (Appendix A).

KEY FIELD

Granville Consolidated Pool, Clinton County, Kentucky

Reservoirs in the Granville Consolidated Pool, Carter coordinate section D-52, Clinton County, are typical of the offshore bars developed on the Middle and Upper

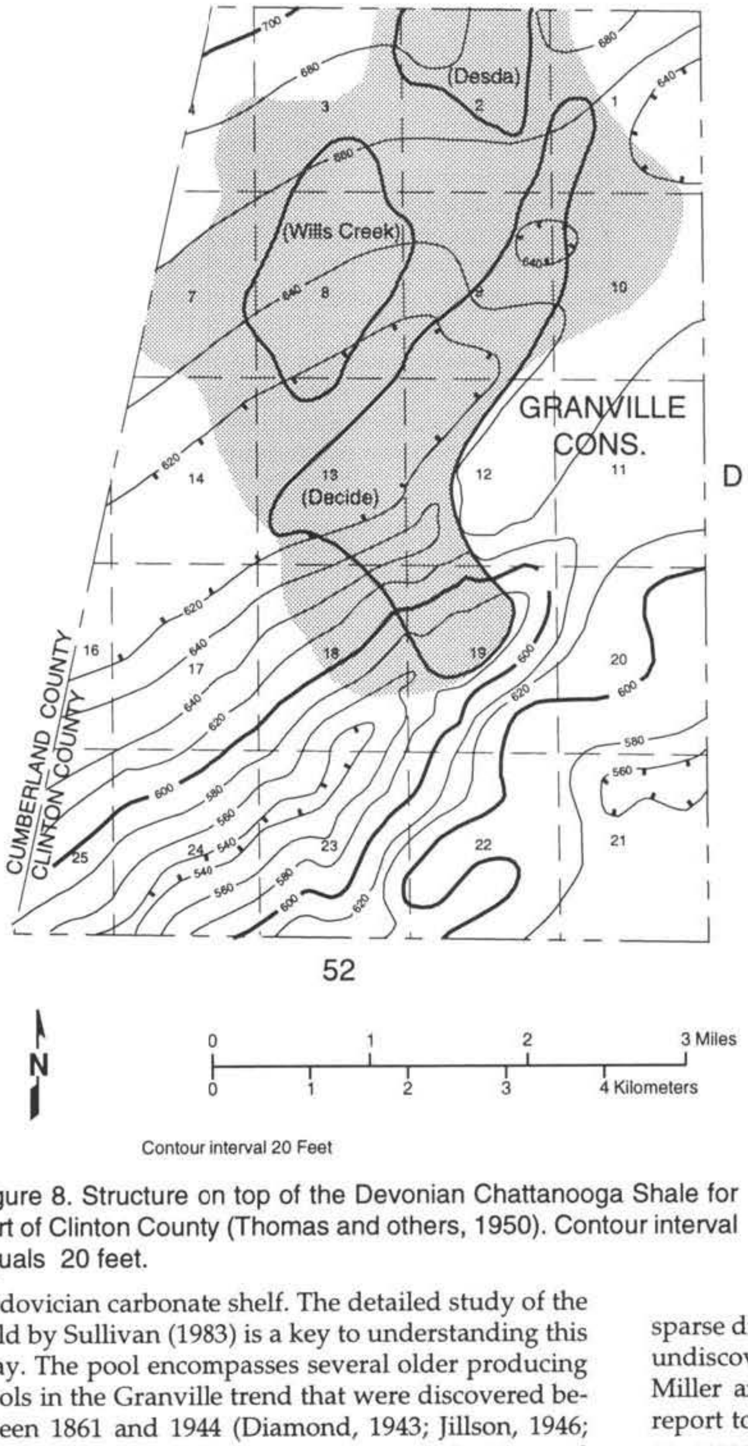

Figure 8. Structure on top of the Devonian Chattanooga Shale for part of Clinton County (Thomas and others, 1950). Contour interval equals 20 feet.

Ordovician carbonate shelf. The detailed study of the field by Sullivan (1983) is a key to understanding this play. The pool encompasses several older producing pools in the Granville trend that were discovered between 1861 and 1944 (Diamond, 1943; Jillson, 1946; Perkins, 1955). The reservoirs in the pool, the First and Second Granville zones, constitute a stacked shoaling sequence (Sullivan, 1983). An isopach map of the First Granville zone is shown in Figure 9 (Sullivan, 1983). The thicker barrier-bar systems have been correlated with areas having the best oil and gas production (Sullivan, 1983). Figure 10 is a north-south cross section through the Granville Consolidated Pool area that illustrates the distribution of the Granville zones and associated hydrocarbon production. Expansion of gas associated with oil production is the primary reservoir drive. An estimated 770 acres produce nonassociated gas, and an estimated 2,000 acres produce oil. The average spacing, by statute, is 1,000 feet between gas wells, although many wells were drilled prior to adoption of the current regulations in 1960, and are spaced 400 feet or less apart. The producing intervals range from 600 to nearly 800 feet in depth, with an average net pay thickness of 9 feet. Calculated from available logs, the average porosity of the producing intervals is 14 percent.

RESOURCES AND RESERVES

Regional production data available at the Kentucky Geological Survey indicate an estimated 50 to 100 MMcf of gas per year is produced from central Kentucky Trenton reservoirs along the western margin of the Appalachian Basin. This estimate does not account for an unknown number of domestic gas supply wells, nor does it account for gas production from Trenton reservoirs in eastern Kentucky pools that is commingled with other producing zones. This general lack of production data makes resource and reserves estimates extremely speculative. Jillson (1946) asserted that as much as 20 to 25 MMcf had been discovered, plugged, and abandoned in the areas of Kentucky he studied. Because of limited reservoir and production data, little is known of the potential for gas in the bioclastic reservoirs of this play in Ohio (Marc Baranoski, Ohio Geological Survey, oral commun., 1994) and West Virginia.

With the potential for additional reservoirs, the proximity of viable source rocks, and sparse drilling in certain localities, this play should have undiscovered recoverable gas resources as defined by Miller and others (1975). The method selected in this report to estimate the undiscovered recoverable gas resources was a statistical-volumetric procedure. Probable limits of the potentially productive argillaceous and clean carbonates deposited in Shermanian and Cincinnatian time are outlined in Figure 1. These areas are estimated to be 72.7 million acres and 23.7 million acres, respectively. Arbitrarily, 50 percent of each potentially productive area was eliminated from consideration. The areas eliminated are located where the reservoir units crop out, are too shallow, are judged too deep to be an economically feasible primary drilling target, or underlie restricted areas such as rivers, cities, and parks. Based on the distribution of current fields, we estimated that 0.5 percent of the remaining acreage would be potentially productive. Resource calculations were performed for each area separately, and then their total resources were aggregated.

Using the guidelines and triangular distribution methods of Megill (1977), absolute minimum, most likely, and absolute maximum production values for millions of cubic feet of gas per acre-foot (MMcf/AcFt); net pay thickness; and productive acreage were selected as the most critical parameters. These data are shown in Table 1. Cumulative frequency distributions were generated from the triangular distribution parameters and used to statistically model the resource parameters for Monte Carlo (random) simulation.

The Monte Carlo simulation was achieved using the RISK program (Cowan, 1984). Each generated cumulative frequency distribution was divided into three classes, with the midpoint of each class chosen as the expected minimum, most likely, and expected maximum values for the simulation. The probability of each class was the calculated frequency of the class from the cumulative frequency distribution. Because of the parameters chosen, the probability of the minimum Monte Carlo simulation value exceeded the probability of the most likely value of the acreage estimates skewing the estimates toward more conservative values. RISK generates a data set of resource estimates by selecting each of the

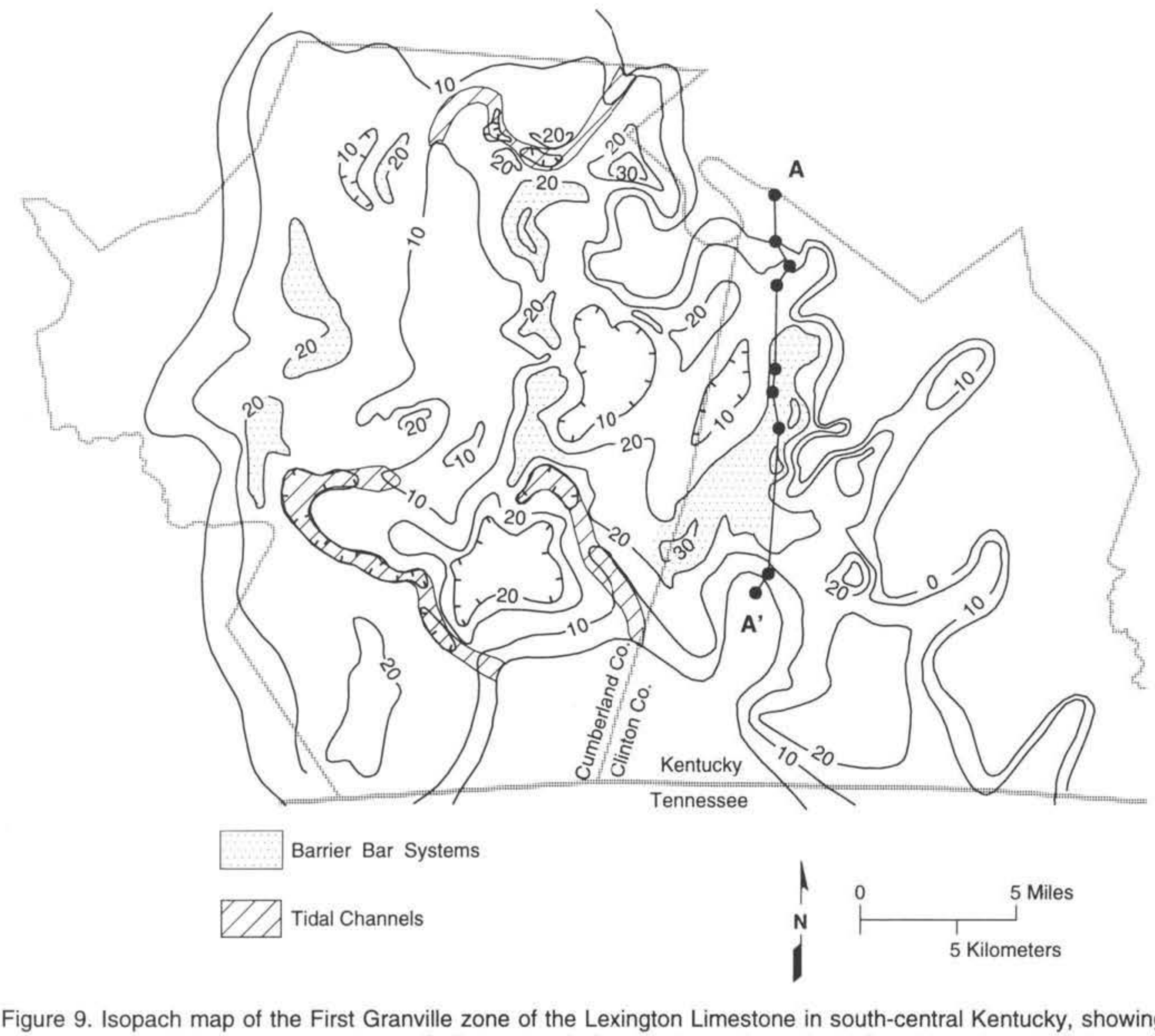

Figure 9. Isopach map of the First Granville zone of the Lexington Limestone in south-central Kentucky, showing barrier bar and tidal channel complexes (Sullivan, 1983). Contour interval equals 10 feet. Line of section shown in Figure 10.

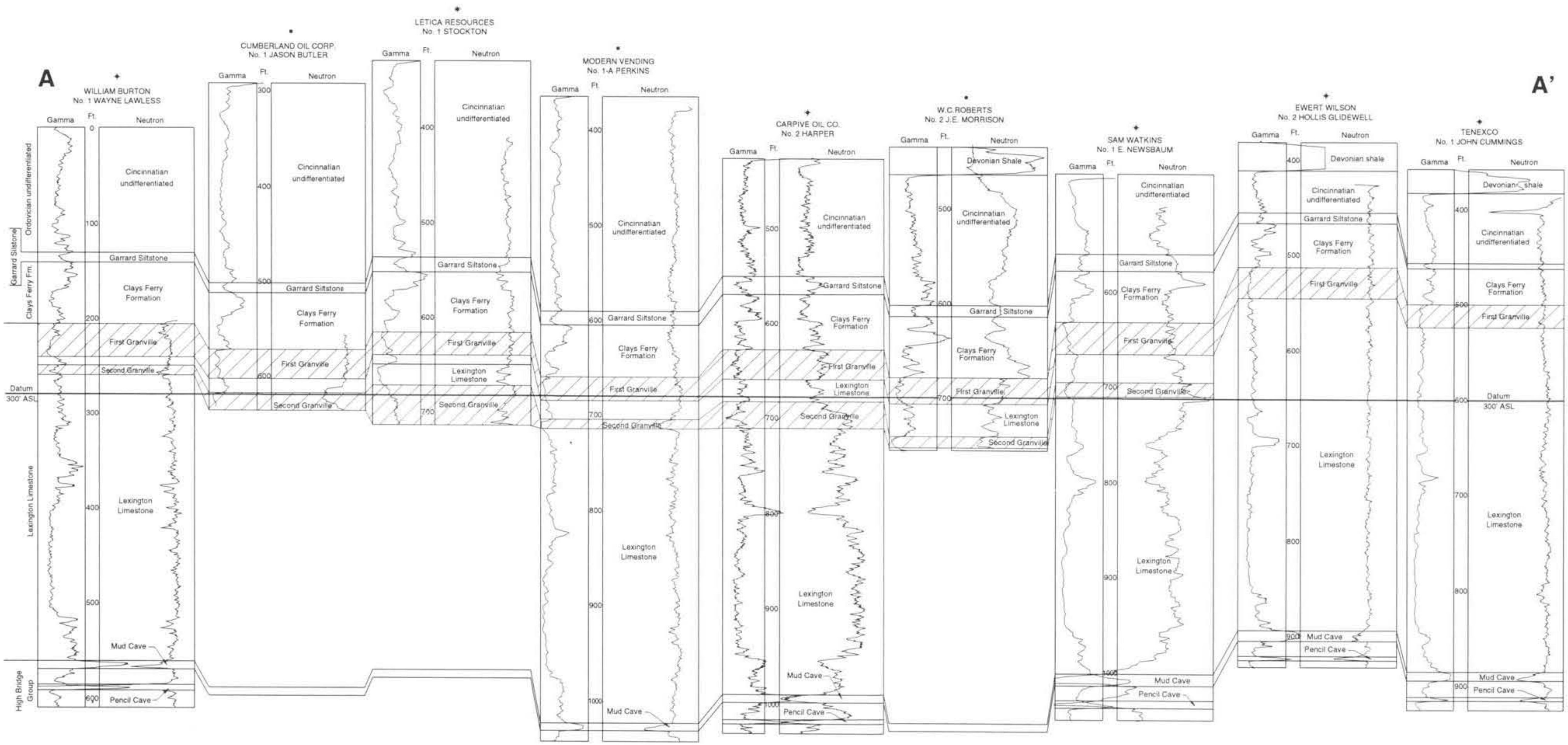

Figure 10. North–south structural cross section of part of Clinton County showing the distribution of Granville zone (diagonal lines) and hydrocarbon production (Sullivan, 1983). See Figure 9 for location.

Table 1. Summary of undiscovered recoverable resource calculations for Ordovician bioclastic carbonate play.

Category	Acreage		Net Pay		Recovery		Resources (Bcf)
	Thousands of Acres	Probability	Thickness (feet)	Probability	Mcf per AcFt	Probability	
Upper Ordovician (exclusive of Lexington/Trenton)							
Minimum	1	50%	2	25%	98	27%	0.2
Most Likely	3	40%	9	65%	327	55%	8.8
Maximum	5	10%	25	10%	556	18%	70.7
10th Percentile							0.8
50th Percentile							2.7
90th Percentile							8.8
Weighted Mean							4
Lexington/Trenton							
Minimum	29	50%	2	25%	98	27%	5.7
Most Likely	92	40%	9	65%	327	55%	270.5
Maximum	155	10%	25	10%	556	18%	2154.50
10th Percentile							25.5
50th Percentile							85.1
90th Percentile							270.5
Weighted Mean							122.8
Total Undiscovered Resources Estimate for Play Obc							
10th Percentile	(90% chance of at least this)						26
90th Percentile	(10% chance of at least this)						279
Total Weighted Mean Undiscovered Recoverable Resources (Bcf)							127

three parameters at the given frequencies of occurrence. This data set is then analyzed for percentiles, means, and other statistics.

The undiscovered recoverable resource estimates for the play are probabilistic and range from 26.3 bcf at the 90 percent level of confidence to 279.3 bcf at the 10 percent level of confidence. That is, there is a 90 percent chance that undiscovered resources are at least 26.3 bcf. The estimated total weighted mean for undiscovered recoverable resources for the Lexington Limestone (Trenton) and Cincinnatian Series combined is 127 bcf (from Monte Carlo simulation).

FUTURE TRENDS

Additional gas-bearing bioclastic reservoirs in the Middle and Upper Ordovician sequence will probably be discovered as lithofacies, structural, and seismic mapping of shoaling sequences improves. Localized structural highs along regional flexures may be a key to finding reservoirs, because the highs may control the location of winnowed bioclastic bars. In general, these reservoirs will probably not be the primary target for future drilling outside of southern and eastern Kentucky along the margin of the basin. Here, the reservoirs are relatively deep (for example, at drilling depths greater than 2,000 feet), and represent subtle stratigraphic features that will be difficult to detect with seismic or remote-sensing methods. However, as exploration and development continues for Lower Ordovician and Upper Cambrian carbonate reservoirs, these bioclastic carbonate bars will merit further evaluation. In addition, given sufficient reservoir seal, they may represent a potential for development as gas storage fields.

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APPENDIX A.
Data on Upper Ordovician Bioclastic Carbonate (Trenton) Limestone Play

Appendix A. Data on Upper Ordovician bioclastic carbonate (Trenton) limestone play.

Play No.	Obc	Obc	Obc	Obc
Pool Name	Albany Cons	Chicken Gizzard	Dry Ridge	Granville Cons
Pool No.	1602248365SBRK	1600421361DRKS	1600591365LXTN	1600809361GRNV
Latitude	36.624989	37.380614	38.688166	36.761656
Longitude	-85.208262	-85.077518	-84.59104	-85.20828
Discovered	1939	1986	1987	1861
Depth to Top Reservoir	497	162	325	711
Age of Reservoir	Ordovician	Ordovician	Ordovician	Ordovician
Producing Reservoir	Sunnybrook	Drakes Fm.	Lexington Ls.	Granville
Lithology	Limestone	Limestone	Limestone	Limestone
Trap Type	Combination	Combination	Combination	Combination
Depositional Environment	Marine	Shallow marine shelf	Marine	Shallow marine shelf
Discovery Well IP (MCF)			10	
Drive Mechanism	Gas	Gas expansion	Gas	Gas expansion
No. Producing Wells	2	14	19	6
No. Abandoned Wells				1
Area (acreage)	150	1050	1680	770
Well Spacing	20	20	20	20
Oldest Formation Penetrated	327KNOX	365MRFB	365LXTN	368KNOX
Expected Heterogeneity Due to Deposition			Dominant	Dominant
Expected Heterogeneity Due to Diagenesis	Locally important	Dominant	Locally important	Dominant
Expected Heterogeneity Due to Fracturing	Dominant	Locally important	Locally important	
Expected Heterogeneity Due to Structure				
Continuity of Reservoir	Unknown	Unknown	Somewhat discontinuous	Continuous
Average Pay Thickness (ft.)	29	5	9	9
Average Completion Thickness (ft.)	13	7	15	18
Average Matrix Density	2.71	2.71	2.71	2.71
Average Porosity—Log (%)			10.0%	14.0%
Minimum Porosity—Log (%)			4.0%	4.0%
Maximum Porosity—Log (%)			13.0%	15.0%
No. of Data Points			4	3
Average Porosity—Core (%)				13.1%
Minimum Porosity—Core (%)				12.2%
Maximum Porosity—Core (%)				14.9%
No. of Data Points				1
Average Permeability				57.1
Minimum Permeability				1.5
Maximum Permeability				293

Appendix A. Data on Upper Ordovician bioclastic carbonate (Trenton) limestone play.

Play No.	Obc	Obc	Obc	Obc
Pool Name	Raccoon Mountain	Seventy-six Cons	Sugar Hill	Trixie Cons
Pool No.	1601600365TRNT	1601766361GRNV	1601920361GRNV	1602002365TRNT
Latitude	37.124989	36.791656	37.132097	37.291655
Longitude	-83.958316	-85.124947	-84.549143	-83.708335
Discovered	1923	1946	1990	1981
Depth to Top Reservoir	2190	695	859	2654
Age of Reservoir	Ordovician	Ordovician	Ordovician	Ordovician
Producing Reservoir	Trenton Ls.	Granville	Granville	Trenton Ls.
Lithology	Limestone	Limestone	Limestone	Limestone
Trap Type	Combination	Combination	Combination	Combination
Depositional Environment	Marine	Marine	Marine	Marine
Discovery Well IP (MCF)	75	60	154	
Drive Mechanism	Gas	Gas	Gas	Gas
No. Producing Wells	1	1	3	2
No. Abandoned Wells		1		
Area (acreage)	20	20	150	100
Well Spacing	20	20	20	20
Oldest Formation Penetrated	327KNOX	361GRNV	361GRNV	365TRNT
Expected Heterogeneity Due to Deposition	Dominant	Dominant	Dominant	Dominant
Expected Heterogeneity Due to Diagenesis	Locally important	Locally important	Locally important	
Expected Heterogeneity Due to Fracturing	Not applicable			Locally important
Expected Heterogeneity Due to Structure	Not applicable			
Continuity of Reservoir	Unknown	Unknown	Unknown	Discontinuous
Average Pay Thickness (ft.)		11	1	12
Average Completion Thickness (ft.)	40	13	1	13
Average Matrix Density	2.71	2.71	2.71	2.75
Average Porosity—Log (%)		11.0%		3.0%
Minimum Porosity—Log (%)		4.0%		2
Maximum Porosity—Log (%)		11.0%		
No. of Data Points		1		
Average Porosity—Core (%)				
Minimum Porosity—Core (%)				
Maximum Porosity—Core (%)				
No. of Data Points				
Average Permeability				
Minimum Permeability				
Maximum Permeability				

Appendix A. Data on Upper Ordovician bioclastic carbonate (Trenton) limestone play.

Play No.	Obc
Pool Name	Windy City
Pool No.	1602139361LPRS
Latitude	36.708322
Longitude	-84.958271
Discovered	1920
Depth to Top Reservoir	500
Age of Reservoir	Ordovician
Producing Reservoir	Leipers Ls.
Lithology	Limestone
Trap Type	Combination
Depositional Environment	Marine
Discovery Well IP (MCF)	500
Drive Mechanism	Gas
No. Producing Wells	1
No. Abandoned Wells	
Area (acreage)	20
Well Spacing	20
Oldest Formation Penetrated	327KNOX
Expected Heterogeneity Due to Deposition	Dominant
Expected Heterogeneity Due to Diagenesis	Locally important
Expected Heterogeneity Due to Fracturing	
Expected Heterogeneity Due to Structure	
Continuity of Reservoir	Unknown
Average Pay Thickness (ft.)	10
Average Completion Thickness (ft.)	10
Average Matrix Density	2.71
Average Porosity—Log (%)	13.0%
Minimum Porosity—Log (%)	4.0%
Maximum Porosity—Log (%)	15.0%
No. of Data Points	1
Average Porosity—Core (%)	
Minimum Porosity—Core (%)	
Maximum Porosity—Core (%)	
No. of Data Points	
Average Permeability	
Minimum Permeability	
Maximum Permeability	

Appendix A. Data on Upper Ordovician bioclastic carbonate (Trenton) limestone play.

Play No.	Obc	Obc	Obc	Obc
Pool Name	Albany Cons	Chicken Gizzard	Dry Ridge	Granville Cons
Avg. Horizontal Permeability				57.1
Avg. Vertical Permeability				
Initial Shut-In Pressure		125	50	
Casing or Tubing	Casing	Casing	Casing	Casing
Hours		24	24	
Present Shut-In Pressure	100	75	50	
Casing or Tubing	Casing	Casing	Casing	Casing
Hours	24	10	24	
Date of Present Pressure	1991	1988	1988	
Earth Pressure Gradient	Underpressured	Underpressured	Underpressured	Underpressured
Reservoir Temperature	66			65
Rw				
Gas Gravity			0.642	
Gas Saturation (%)				
Water Saturation (%)				
Commingled	Yes	No	No	No
Associated or Nonassociated	Nonassociated	Nonassociated	Nonassociated	Nonassociated
Heating Value (Btu)			1002	
Status (Producing, Abandoned, Storage)	Producing	Producing	Producing	Producing
Production Data Initial Year				
Production Data Final Year				
Cumulative Production (Mcf)				
No. Wells				
Original Gas in Place (Mcf)				
Original Gas Reserves (Mcf)				
Remaining Gas In Place (Mcf)				
Remaining GIP Year				
Remaining Gas Reserves (Mcf)				
Remaining Reserves Year				
Average IOF (Mcf/d)				
Average FOF (Mcf/d)	105	294	314	8
Recovery Factor (%)				
Typical Logs	No logs	None available	GR/FDC/TEMP	GRD
Typical Completion Practice	7" @ 450'; open hole; natural	6 5/8" @120'; natural; open hole; 5 well	7" @ 90'; open hole; natural	4 1/2" @ 700'; 500 gal. acid over zone
Comments	Est. pay thick from driller's report	All wells prd. Drakes Fm.		Several wells used as gas

Appendix A. Data on Upper Ordovician bioclastic carbonate (Trenton) limestone play.

Play No.	Obc	Obc	Obc	Obc
Pool Name	Raccoon Mountain	Seventy-six Cons	Sugar Hill	Trixie Cons
Avg. Horizontal Permeability				
Avg. Vertical Permeability				
Initial Shut-In Pressure	300	50	260	
Casing or Tubing	Casing	Casing	Casing	Casing
Hours	24			
Present Shut-In Pressure				
Casing or Tubing	Casing	Casing	Casing	Casing
Hours				
Date of Present Pressure				
Earth Pressure Gradient	Underpressured	Underpressured	Underpressured	Underpressured
Reservoir Temperature			65	
Rw				
Gas Gravity				
Gas Saturation (%)				
Water Saturation (%)				
Commingled	Yes	No	No	No
Associated or Nonassociated	Nonassociated	Nonassociated	Nonassociated	Nonassociated
Heating Value (Btu)				
Status (Producing, Abandoned, Storage)	Producing	Producing	Producing	Producing
Production Data Initial Year			1990	
Production Data Final Year			1992	
Cumulative Production (Mcf)			20,000	
No. Wells			3	
Original Gas in Place (Mcf)				
Original Gas Reserves (Mcf)				
Remaining Gas In Place (Mcf)				
Remaining GIP Year				
Remaining Gas Reserves (Mcf)				
Remaining Reserves Year				
Average IOF (Mcf/d)	75			
Average FOF (Mcf/d)		55	53	
Recovery Factor (%)				
Typical Logs	None	GR/FDC	None	FDC?NBC/GR
Typical Completion Practice	7" @ 768': open hole; natural	7" @ 418'; open hole; natural	7" @ 500'; open hole' natural	7" @ 850'; open hole; 1000 ga. acid
Comments	Pay est. from driller's report		Pay est. from driller's report	

Appendix A. Data on Upper Ordovician bioclastic carbonate (Trenton) limestone play.

Play No.	Obc
Pool Name	Windy City
Avg. Horizontal Permeability	
Avg. Vertical Permeability	
Initial Shut-In Pressure	100
Casing or Tubing	Casing
Hours	
Present Shut-In Pressure	
Casing or Tubing	Casing
Hours	
Date of Present Pressure	
Earth Pressure Gradient	Underpressured
Reservoir Temperature	
Rw	
Gas Gravity	
Gas Saturation (%)	
Water Saturation (%)	
Commingled	No
Associated or Nonassociated	Nonassociated
Heating Value (Btu)	
Status (Producing, Abandoned, Storage)	Producing
Production Data Initial Year	
Production Data Final Year	
Cumulative Production (Mcf)	
No. Wells	
Original Gas in Place (Mcf)	
Original Gas Reserves (Mcf)	
Remaining Gas In Place (Mcf)	
Remaining GIP Year	
Remaining Gas Reserves (Mcf)	
Remaining Reserves Year	
Average IOF (Mcf/d)	
Average FOF (Mcf/d)	500
Recovery Factor (%)	
Typical Logs	GR/FDC
Typical Completion Practice	8 1/4" @ 13'; 6 14" @ 288'
Comments	Completed as domestic gas

MISSION STATEMENT

The Kentucky Geological Survey at the University of Kentucky is a State-mandated organization whose mission is the collection, preservation, and dissemination of information about mineral and water resources and the geology of the Commonwealth. KGS has conducted research on the geology and mineral resources of Kentucky for more than 150 years, and has developed extensive public databases for oil and gas, coal, water, and industrial minerals that are used by thousands of citizens each year. The Survey's efforts have resulted in topographic and geologic map coverage for Kentucky that has not been matched by any other state in the Nation.

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