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U.S. GEOLOGICAL SURVEY

Petroleum Exploration Plays and Resource Estimates, 1989, Onshore United States-- Region 8, Eastern Interior; Region 9, Atlantic Coast

By

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PETROLEUM EXPLORATION PLAYS AND RESOURCE ESTIMATES, 1989, ONSHORE UNITED STATES-- REGION 8, EASTERN INTERIOR; REGION 9, ATLANTIC COAST

Richard B. Powers, *Editor*

INTRODUCTION

By Richard B. Powers

This report, combining assessment Regions 8 and 9, is the final one of a series, and provides brief discussions of the petroleum geology, play descriptions, and hydrocarbon resource estimates of 26 individually assessed exploration plays in 10 onshore geologic provinces in assessment Region 8, Eastern Interior and Region 9, Atlantic Coast, within the continental United States. These 10 provinces were among 80 onshore provinces, including 220 plays, that were assessed in connection with the determination of the Nation's estimated undiscovered resources of oil and gas in 1989. The report is an outgrowth of, and is based on, studies that led to the publication of "Estimates of undiscovered conventional oil and gas resources in the United States--A part of the Nation's energy endowment" (Mast and others, 1989). That report, a cooperative effort by the USGS (U.S. Geological Survey) and MMS (Minerals Management Service), presented estimates of undiscovered conventionally recoverable oil and gas for both the onshore and offshore petroleum provinces of the Nation. The data sources, assumptions, and methodologies used in the development of these estimates are summarized in Mast and others (1989) and described in more detail in a joint USGS-MMS Working Paper, U.S. Geological Survey Open-File Report 88-373 (1988). The plays discussed in this final report are those that are located exclusively within the onshore United States and adjoining State offshore areas, as assessed by the USGS. All estimates of undiscovered oil and gas resources are as of January 1, 1987; additional data received after that date were not incorporated into the assessment.

In the 1989 National appraisal of undiscovered oil and gas resources, plays were the basic unit for quantitative estimates; this report presents not only the play estimates, but also the framework and petroleum geology for each of these basic units. Play discussions here summarize the open-file reports which were prepared by the geologists assigned to each assessment area. We are presenting the resource estimates and narrative descriptions at this basic play level because of the great interest shown by the public, State Geological Surveys, the oil and gas industry, and workers involved in oil and gas appraisal.

Sources of information for province studies included published and purchased data, data from USGS studies in progress, data from previous resource assessments, data from State Geological Surveys, and analysis of geological, geochemical, and geophysical data from various sources utilized in developing and defining plays. Computerized drilling and well completion data from oil and gas exploratory and development wells came from PI WHCS (Petroleum Information Corporation's Well History Control System). In addition, data on oil and gas fields were obtained from the "Significant oil and gas fields of the United States" file of NRG Associates, Inc. of 1986, and from the PI PDS (Petroleum Information Corporation's Petroleum Data System) computerized file of 1986. Additional statistical information on field production and reserves was obtained from yearly publications of various State oil and gas commissions, or their equivalents.

Uncertainties are inherent in estimating undiscovered quantities of oil and gas. Play estimates presented here are judgmental and are based upon a variety of geologic data, records of exploration successes and failures, production histories, assumptions of economic and technical conditions, and appraisal methods. Methodologies were developed to aid in making decisions under conditions of uncertainty, and the results are presented as ranges of values with associated probabilities of occurrence. The estimates should be viewed as indicators, not absolutes, of the petroleum potential of the plays. The plays range from those in mature, established producing basins, to highly speculative, frontier-type plays in provinces that have experienced scant exploration or wildcat drilling.

COMMODITIES ASSESSED

Commodities assessed in this study are crude oil, natural gas, and natural gas liquids that exist in conventional reservoirs. Terms defined here are standard usage of the the oil and natural gas industry and resource estimation.

Undiscovered recoverable resources.--Resources in undiscovered accumulations, analogous to those in existing fields, which are producible with current recovery technology and efficiency, but without reference to economic viability. These resources occupy the area of the heavily framed box in figure 1.

Conventional resources.--Resources included in this category are crude oil, natural gas, and natural gas liquids that exist in reservoirs or in a fluid state amenable to extraction techniques employed in traditional development practices. They occur as discrete accumulations. They do not include oil occurring within extremely viscous and intractable heavy oil deposits, tar deposits, oil shales, gas from low-permeability "tight" sandstone and fractured shale reservoirs having *in situ* permeabilities to gas of less than 0.1 millidarcy, coal bed methane, gas in geopressured shales and brines, or gas hydrates.

AREAS OF STUDY

The primary organization of this study is by region as defined in figure 2 and as used in Mast and others (1989). Discussions of the Eastern Interior, Region 8, and Atlantic Coast, Region 9, begin with a description of their geologic frameworks, modified from Mast and others (1989). Discussion of provinces in the regions follows; the format for each province includes an introduction covering the geologic setting, exploration history, age of sediments, and a generalized stratigraphic chart. (No stratigraphic chart is provided for a province where no individual plays were assessed; a map of the province is substituted, because no specific stratigraphy is discussed in that province.) Following each province introduction is a systematic discussion of its individual plays. The play format includes the play name, narrative discussion and two illustrations, (1) a province map with the area of the play emphasized, and (2) a tabular form showing the original input data for the play appraisal.

Areas of State but not Federal waters are included in the assessment of adjacent onshore regions and provinces. The boundaries of State waters are 3 nautical miles offshore for the Pacific and Atlantic coasts and for the Alabama coast of the Gulf of Mexico. Louisiana and Mississippi have decreed State water boundaries that vary slightly from 3 nautical miles. For the Texas and Florida coasts of the Gulf of Mexico, the boundaries of State waters are 3 marine leagues (10.36 statute miles) offshore. In addition, all maritime boundaries and limits depicted on maps in the report are for initial planning purposes only, and do not prejudice or affect United States jurisdiction in any way.

Regions are basically geographic in character; however, their outlines are an attempt to group individual provinces along broad geologic lines. Provinces are constructed around natural

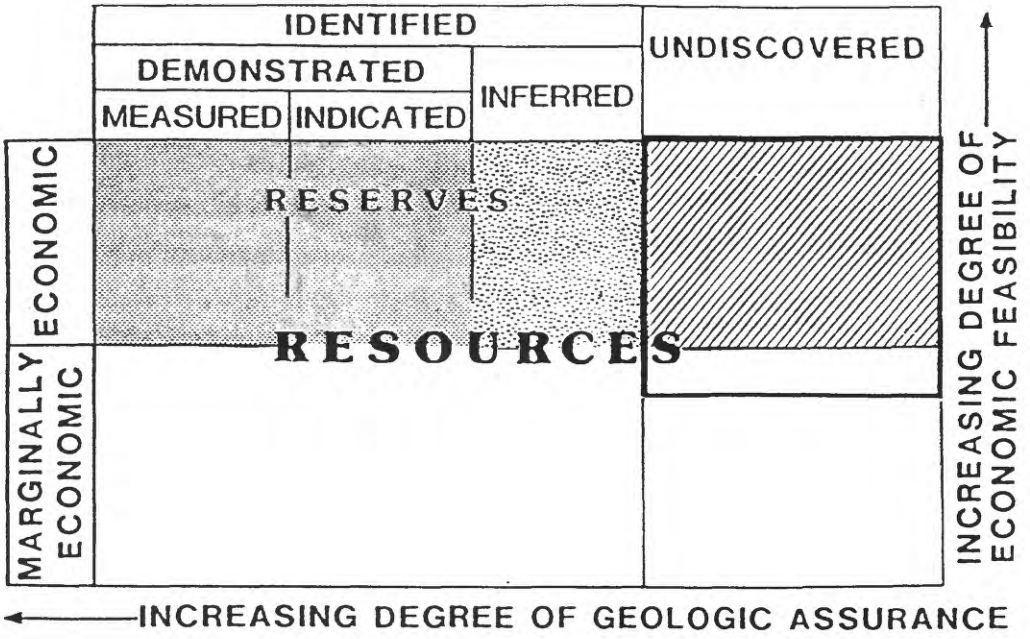

Figure 1. Diagrammatic representation of petroleum resource classification (Mast and others, 1989) representing conventional oil and gas resources. Area with heavy frame on upper right represents undiscovered recoverable resources estimated in this study.

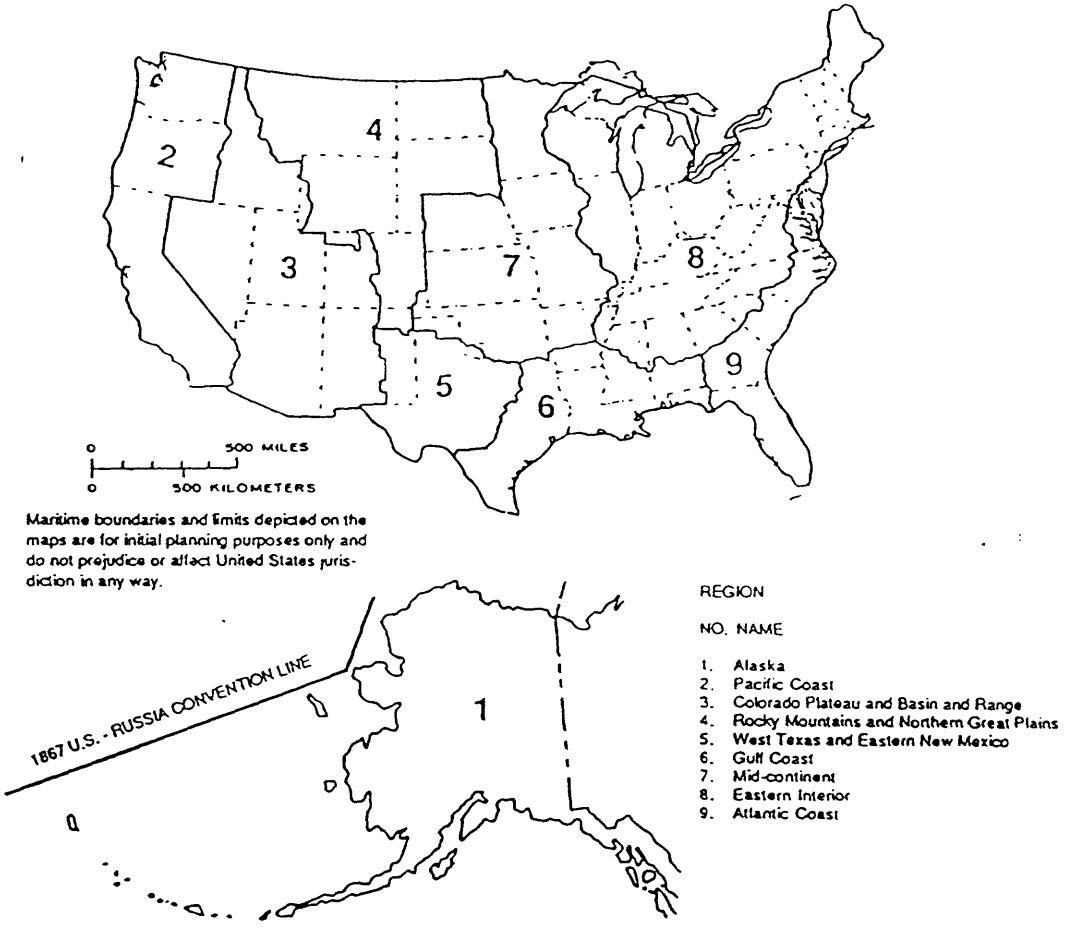

Figure 2. Map showing petroleum regions assessed in this study. Heavy lines are region boundaries, dotted lines are State boundaries.

geologic entities and may include a single dominant structural element, or a number of contiguous elements; they are named for structural or geographic features within their boundaries. These boundaries, following State and county lines, wherever possible, facilitate the use of production, reserves, and other reported data. A play is named after the most dominant feature or characteristic of a structural, stratigraphic, or geographic nature that best identifies it. Its name can also apply to a concept. Many plays described herein are recognized from their titles by the petroleum industry, but play titles are in no way formal geologic or stratigraphic names.

PLAY DISCUSSION FORMAT

Individual plays described and assessed in this report include only those that were estimated to have undiscovered accumulations greater than 1 MMBO (million barrels of oil) or 6 BCFG (billion cubic feet of gas). Plays judged to have undiscovered accumulations that fell below that threshold were assessed separately for the provinces as a whole, and are not described in the report. A play is defined as a group of geologically related known or undiscovered accumulations and(or) prospects having similar characteristics of hydrocarbon source, reservoir, trap, and geologic history.

In order to achieve some degree of consistency in narrative discussions of a great number and variety of plays, a topical outline based on the definition of an exploration play has been used. Each play discussion notes the play characteristics, followed by descriptions of (1) reservoirs, (2) source rocks and related geochemistry, (3) timing of generation and migration of hydrocarbons, (4) traps (types, sizes, seals, and drilling depths), (5) exploration status (history, discovered volumes, field sizes, and hydrocarbon types), and (6) qualitative future hydrocarbon potential and factors limiting that potential. Although the discussions adhere to the order of the topical outline, it will be apparent that some inconsistency occurs in the amount of detail and coverage of each topic from one play to another. This is due to the relative abundance or lack of data pertinent to each play and is unavoidable in a report of this scope. Play discussions here are, of necessity, brief summaries. More detailed play information can be found in the province open-file reports, which are listed in the references at the end of each Region. Each play title is followed by a sequence number (for example, Rough Creek Graben Play (050)), and these also appear on the table of resource estimates.

ASSESSMENT PROCEDURES AND METHODS

Assessments of undiscovered recoverable oil and gas in the individual plays in each province, and resources in small (< 1 MMBO or < 6 BCFG) accumulations were based upon review and analysis of the petroleum geology and exploration history of each province and incorporated geologic and geophysical information available as of January 1, 1987. In the National assessment, 220 plays covering the onshore and adjoining State offshore areas were identified, and for each individual play, undiscovered oil and gas resources were estimated. Plays judged to contain more than 1 MMBO or 6 BCFG were individually assessed; plays judged to contain less than those amounts were treated differently, as described below. See Mast and others (1989) and USGS/MMS (1988) for a detailed discussion of this assessment, its assumptions, methods, and results.

In the play analysis method, geologic settings of oil and gas occurrence are modeled. The play is treated as a collection of accumulations (pools, fields) of similar geologic risk sharing common geologic characteristics that include reservoir and source rocks and known or suspected trapping conditions. A team of geoscientists made judgments as to the probability of the occurrence of those geologic factors necessary for the formation of hydrocarbon accumulations, and quantitatively assessed each factor as a play attribute; the team then estimated the numbers and sizes of accumulations as probability distributions, conditional on favorable play attributes.

All of this information was entered on the play data input form which is included in each play discussion in this report. The information was then analyzed by a team who developed a computer program that performed the resource calculations on the basis of the assessment information in the input form, employing an analytical method based on probability theory. Final, undiscovered oil and gas estimates for each play, based on this method, are shown on Table 1 at the end of Region 8, and Table 2 at the end of Region 9.

Probabilistic estimates of recoverable oil and gas in accumulations smaller than the established size cut-off (1 MMBO, 6 BCFG) were made separately. These estimates of small accumulations were based primarily on log-geometric extrapolations of numbers of fields into field-size classes smaller than the cut-offs. Estimates of undiscovered resources for these small fields were made for the province as a whole, rather than for the individual plays. These are shown in the table of estimates as: Oil < 1 MMB and Gas < 6BCF. In addition, minor plays and very mature, or nearly depleted plays not assessed individually are included in the table of estimates as: Other Occurrences > 1 MMBO and Other Occurrences >6 BCFG. Ratios of associated-dissolved gas to oil, and NGL (natural gas liquids) to gas, were estimated from historical production data and used for calculation of these components.

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GLOSSARY

Play.--A group of geologically related known or undiscovered accumulations and (or) prospects having similar characteristics of hydrocarbon source, reservoir, trap and geologic history.

Field.--A single pool or multiple pools of hydrocarbons grouped on, or related to, a structural or stratigraphic feature.

Prospect.--A geologic feature having the potential for trapping and accumulating hydrocarbons.

Crude oil.--A mixture of hydrocarbons present in underground reservoir rocks that is in a liquid state and remains in a liquid state as it is produced from wells.

Associated gas.--Free natural gas, occurring as a gas cap, in contact with and above an oil accumulation within a reservoir.

Dissolved gas.--Natural gas dissolved in crude oil within a reservoir.

Nonassociated gas. (*NA*)--Natural gas that is neither associated with nor in contact with crude oil within a reservoir.

Natural gas liquids (NGL).--Those portions of reservoir gas that are liquified at the surface in lease separators, field facilities, or gas processing plants. NGL is reported only in the tables of estimates in this report.

MMBO.--Millions (10^6) of barrels of oil (standard stock tank barrels of crude oil, 42 gallons per barrel).

BBO.--Billions (10^9) of barrels of oil.

BCFG.--Billions (10^9) of cubic feet of gas (standard cubic feet of gas at 14.73 pounds per in^2 and 60°F). Hydrocarbon gases only.

TCFG.--Trillions (10^{12}) of cubic feet of gas. Hydrocarbon gases only.

MMBOE.--Millions of barrels of oil equivalent (conversion factor utilized is 6,000 ft^3 of gas = 1 BOE).

REGION 8--EASTERN INTERIOR

GEOLOGIC FRAMEWORK

By Richard B. Powers

Region 8 is subdivided into 8 provinces, 127-134 (fig. 3). The total number of individually assessed plays in the Region is 25. Undiscovered oil and gas resources in the Sioux Uplift province (124) were assessed under the Iowa Shelf province (125), and both provinces are treated in a single discussion. In addition, one play that occurs within 3 provinces (Piedmont, 133, New England-Adirondack, 134, and Atlantic Coastal Plain, 135 of Region 9) is included under the Piedmont province discussion.

Region 8 comprises several large basins and uplifts within the eastern part of the craton. Two major intracratonic basins, the Michigan (127) and Illinois (128) basins, are separated from the Appalachian basin to the east by the Cincinnati Arch (129) and Nashville Dome. The east side of the foreland Appalachian basin (131) is bounded by the highly deformed rocks of the Blue Ridge Thrust Belt Province (132).

The major producing areas in the region are the Appalachian, Michigan, and Illinois basins. Reservoirs in these basins include both sandstones and carbonates, ranging in age from Cambrian to Pennsylvanian. Not only are structural traps important, but much oil and gas is trapped stratigraphically. Although exploration is in a very mature stage in this region, significant undiscovered resources are believed to exist. Currently, important discoveries are being made in deep Ordovician clastic reservoirs and in Silurian pinnacle reefs of the Michigan basin.

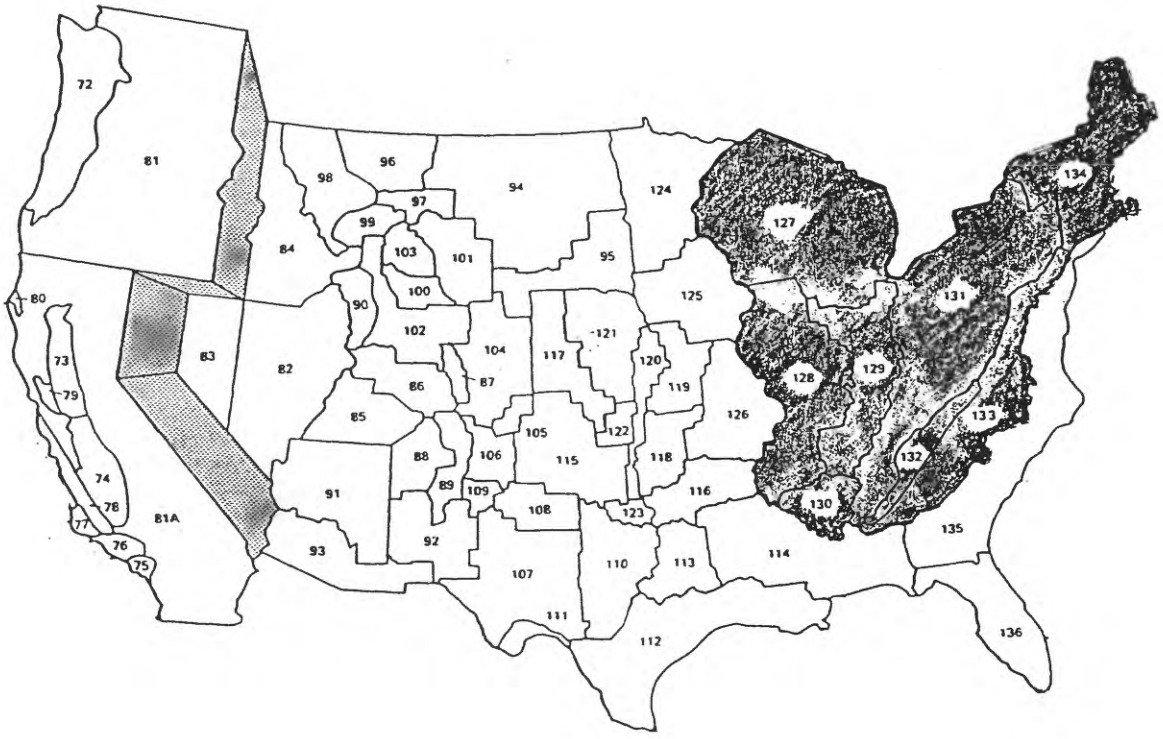

Figure 3. Index map of lower 48 states showing provinces assessed in Region 8 (shaded). Names of provinces are listed by number in table of estimates.

MICHIGAN BASIN PROVINCE (126)

By Ronald R. Charpentier

INTRODUCTION

The Michigan basin province includes the entire States of Michigan and Wisconsin, 12 counties in northeast Indiana, 5 counties in northwest Ohio, and the U.S. portions of the adjoining Great Lakes. The stratigraphic section is up to 15,000 ft thick and consists primarily of clastic and carbonate rocks of Cambrian to Pennsylvanian age (fig. 4). The Michigan basin is a classic, circular interior cratonic basin whose edges are defined by a series of structural highs. Counterclockwise from the west these are the Wisconsin Dome, Wisconsin Arch, Kankakee Arch of Indiana, Findlay Arch of Ohio, and the Canadian Shield. The total area of the province is 164,000 mi^2, of this, only 122,000 mi^2 are underlain by sedimentary rock. The province has been productive of oil and gas since the mid-1880's, however, significant production began in the central part of the basin in 1925. As of 1984, cumulative production totaled greater than 958 MMBO, mainly from Devonian, Silurian, and Ordovician rocks, and 2.3 TCFG, mainly from Silurian, Ordovician, and Mississippian rocks. Eight plays were individually assessed in the province: Offshore Devonian Anticlinal (020), Onshore Devonian Anticlinal (030), Trenton-Black River, (040) Southern Onshore Niagaran Reef (050), Northern Onshore Niagaran Reef (060), Offshore Niagaran Reef (070), Prairie du Chien (080), and Cambrian (090).

System	Stratigraphic Unit
Jurassic	Unnamed redbeds
Pennsylvanian	Grand River Formation
	Saginaw Formation
Mississippian	Grand Rapids Group
	Marshall Sandstone
	Sunbury Shale
Devonian	Berea Sandstone
	Bedford Shale
	Antrim Shale
	Traverse Group
	Rogers City Limestone
	Dundee Limestone
	Detroit River Group
	Bois Blanc Formation
	Garden Island Formation
Silurian	Bass Islands Group
	Salina Group
	Niagara Group
	Cataract Group
Ordovician	Richmond Group (Utica Shale at base)
	Trenton Group
	Black River Group
	St. Peter Sandstone
	Prairie du Chien Group
Cambrian	Trempe leau Formation
	Munising Formation
	Jacobsville Sandstone
Precambrian	

Figure 4. Generalized stratigraphic column, Michigan Basin province.

OFFSHORE DEVONIAN ANTICLINAL PLAY (020)

The play consists mainly of probable structural traps in the offshore areas of a series of onshore northwest- southeast-trending anticlines. The play area covers an area of approximately 10,000 mi^2 (fig. 5). Although there are currently no discovered fields or production in the play, it is the offshore extension of the productive onshore, Devonian Anticlinal play (030), which is a major source of oil and gas in the Michigan basin. Undiscovered hydrocarbons are anticipated to be mainly from Devonian rocks, but smaller amounts of production from Silurian and Mississippian reservoirs would also be expected. Not included, though, are gas reservoirs of the Mississippian and Prairie du Chien, even where they might occupy the same anticline with anticipated Devonian production. Instead, these two are treated as separate plays. Expected reservoir rocks would be mostly porous limestones and, occasionally, dolomitized limestones. Pay thicknesses should generally average about 10 ft. Traps would be mostly anticlinal, but a small number of structural- stratigraphic and stratigraphic traps in Devonian reservoirs might also occur. Seals would be shales and anhydrites within the section. Drilling depths of 1,500 to 7,000 ft would be expected.

Studies of oil geochemistry in the Michigan basin suggest a relationship between oils found in the Ordovician Trenton Group and those found in the Devonian Dundee Limestone. The unusual chemistry suggests an Ordovician source, but this would require migration through the Silurian evaporite sequence. Oils from the younger Devonian Traverse Group seem to be primarily from an unidentified Devonian source with some contribution from Ordovician-sourced oil. Ordovician source rocks could have begun generating oil as early as Silurian time, and Devonian source rocks may have been mature as early as Mississippian time.

Offshore drilling is prohibited at present, but extension of onshore anticlinal trends suggests that a fair offshore potential exists, especially beneath Saginaw Bay, Michigan (fig. 5).

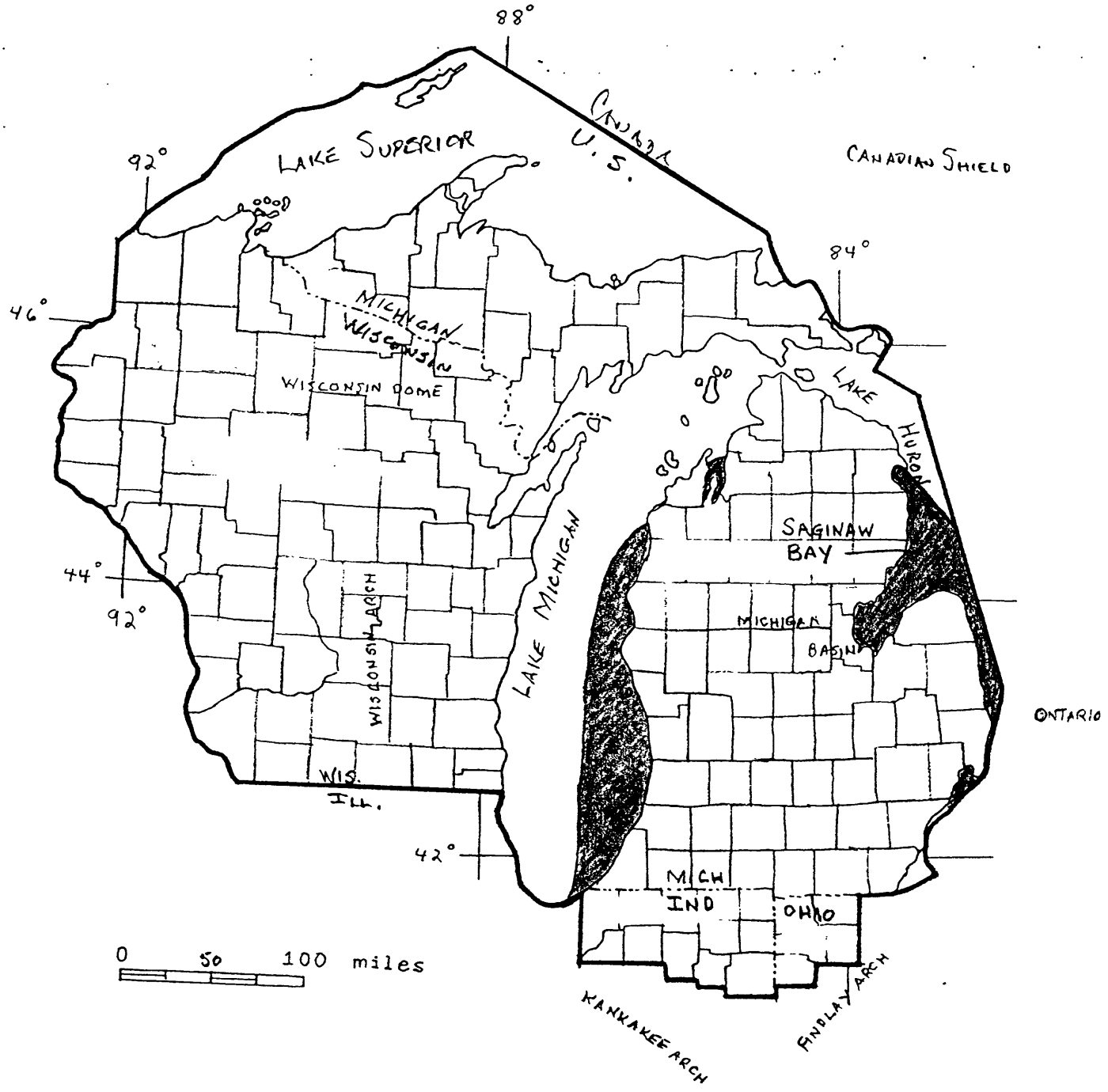

Figure 5. Map of Offshore Devonian Anticlinal play.

OIL AND GAS PLAY DATA

PLAY **OFFSHORE DEVONIAN ANTICLINAL**
PROVINCE **MICHIGAN BASIN** CODE **08-127-020**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.2**	**2.1**	**4**	**8.3**	**26**	**75**
Gas (x 10^9 CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth (x10^3 ft)							
Oil	**1.5**			**3.5**			**7**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**4**	**5**	**6**	**8**	**10**	**14**	**20**

Average ratio of associated-dissolved gas to oil (GOR)	**1000**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

ONSHORE DEVONIAN ANTICLINAL PLAY (030)

The play consists primarily of oil and gas in Devonian carbonate reservoirs in structural accumulations in a series of northwest-southeast-trending anticlines. The play covers about 75,000 mi^2 (fig. 6). Although production is mainly from Devonian rocks, smaller amounts of production from other accumulations in Silurian and Mississippian reservoirs are also included in the play. Not included are gas reservoirs in Mississippian rocks and in the Ordovician Prairie du Chien, even where they occupy the same anticline that has Devonian production. Production has mainly been from the center and southwest parts of the Michigan basin. Reservoir rocks are porous limestones and, occasionally, dolomitized limestones. Pay thicknesses average about 10 ft. Traps are mostly anticlinal, but a small number of structural- stratigraphic and stratigraphic traps are included. Seals are shales and anhydrites within the section. Depth to production of Devonian reservoirs is generally 1,500 to 7,000 ft, but untested reservoirs could be slightly deeper.

Studies of oil geochemistry in the Michigan basin suggest a relationship between oils found in the Ordovician Trenton Group and those found in the Devonian Dundee Limestone. The unusual chemistry suggests an Ordovician source but this would require migration through the Silurian evaporite sequence. Oils from the younger Devonian Traverse Group appear to be primarily from an unidentified Devonian source with some contribution from Ordovician sources. Ordovician source rocks could have begun generating oil as early as Silurian time, and Devonian source rocks may have been mature as early as Mississippian time.

Production from Devonian reservoirs in the Michigan basin dates from 1927. Since that time, about 350 fields have been discovered, about 75 of which are greater than 1 MMBO in size; the largest is greater than 50 MMBO in size. This play includes the largest fields in the basin except for the Albion-Pulaski-Scipio field. Cumulative production for all fields as of 1984 was approximately 550 MMBO and over 140 BCFG. Drilling of major structures in the anticlinal trend has been extensive and discovery rates are presently low; the future potential for additional discoveries in the play is low to moderate.

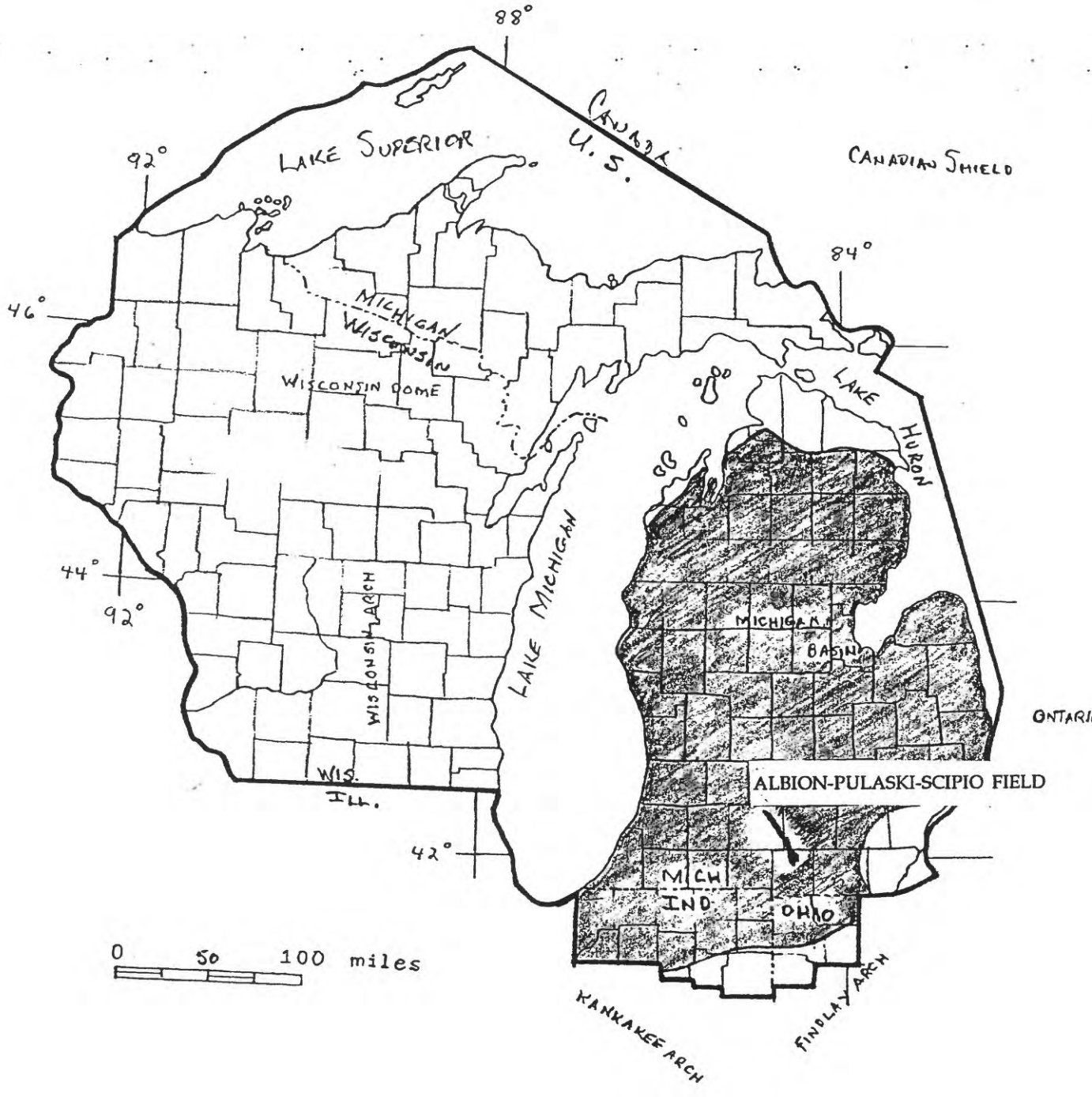

Figure 6. Map of Onshore Devonian Anticlinal play.

OIL AND GAS PLAY DATA

PLAY **ONSHORE DEVONIAN ANTICLINAL**
PROVINCE **MICHIGAN BASIN** CODE **08-127-030**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1×10^{6} BBL; gas, 6×10^{9} CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil ($\times 10^{6}$ BBL)	**1**	**1.1**	**1.5**	**2**	**3**	**7**	**15**
Gas ($\times 10^{9}$ CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth ($\times 10^{3}$ ft)							
Oil	**1.5**			**3.5**			**7**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**5**	**6**	**8**	**10**	**13**	**17**	**20**

Average ratio of associated-dissolved gas to oil (GOR)	**1000**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^{6} CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^{6} CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

TRENTON-BLACK RIVER PLAY (040)

The play is characterized by hydrocarbon accumulations in stratigraphic traps in dolomitized limestone reservoirs within the Middle Ordovician Trenton and Black River Groups on and offshore. The play covers 90,000 mi^2 (fig.7) and includes the largest field in the Michigan basin, the Albion-Pulaski-Scipio trend, as well as the oldest production, (1885). Rocks of these two groups extend over the entire Lower Peninsula and parts of the Michigan Upper Peninsula and Wisconsin but, to date, almost all discoveries have been from the southern part of Michigan's Lower Peninsula, as well as the Indiana and Ohio parts of the basin. Discovered fields are stratigraphic traps resulting from porosity and permeability variations in dolomitized limestone. Dolomitization is localized, however, by fault and fold trends which seem to be generally related to the same northwest-southeast Devonian anticlinal trends (play 030). Pay thickness varies greatly but averages about 30 ft. Drilling depths are fairly shallow; most fields produce from less than 5,000 ft, but undiscovered accumulations could be considerably deeper.

Ordovician oils form a group with the Devonian Dundee oils and have a distinctive chemical composition as found in Ordovician oils from various localities worldwide. The most likely source rock is the Utica Shale (Upper Ordovician) whose correlative in the Canadian part of the basin (Collingwood Member of the Lindsay Formation) was suggested as the source of the Canadian Ordovician oils. Shales in the Utica could have been mature as early as Silurian time.

Earliest production was from a few small fields at the southern edge of the basin which were discovered in the late 19th century. In 1957, the Albion-Pulaski-Scipio trend was discovered in south-central Michigan. This field, the largest in the basin, is approximately 170 MMBOE in size and dominates production statistics for the play. To date, about 50 fields have been discovered in Trenton-Black River rocks. Of these, approximately four are greater than 1 MMBO in size. Cumulative production in the play, as of 1984, was over 125 MMBO and greater than 230 BCFG. The sparseness of drilling in the play allows for significant exploration potential. The key question is whether any large traps similar to the Albion-Pulaski-Scipio trend exist, or if the undiscovered resources would be distributed mainly in small fields (<1 MMBO or <6 BCFG) similar to most of the other fields in the play. The future potential is estimated to be low to moderate.

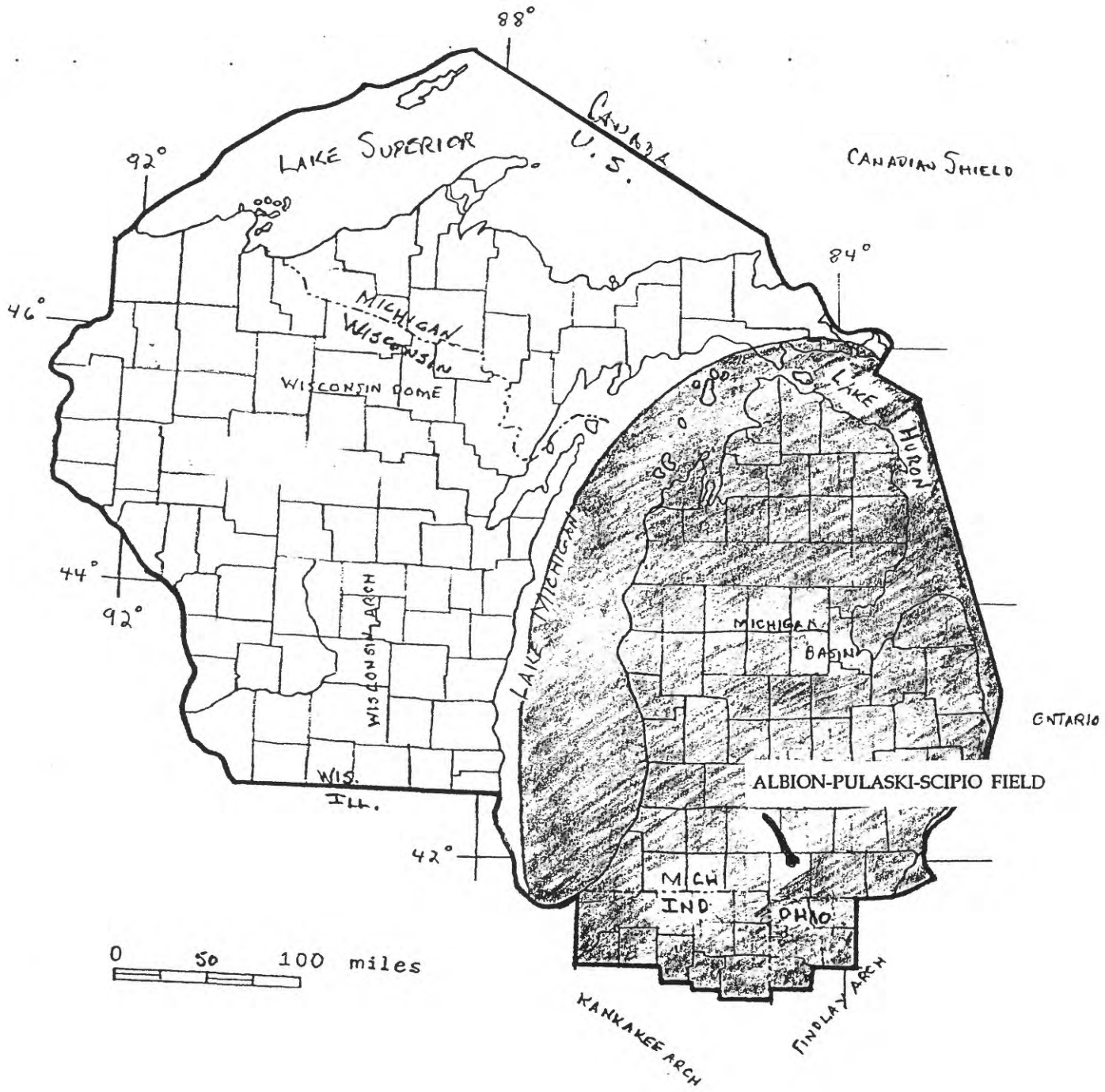

Figure 7. Map of Trenton-Black River play.

OIL AND GAS PLAY DATA

PLAY **TRENTON-BLACK RIVER**
PROVINCE **MICHIGAN BASIN** CODE **08-127-040**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.1**	**1.3**	**2**	**5**	**10**	**25**
Gas (x 10^9 CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth (x10^3 ft)							
Oil	**3**			**4.5**			**11**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**3**	**4**	**7**	**10**	**14**	**20**	**60**

Average ratio of associated-dissolved gas to oil (GOR)	**2000**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

SOUTHERN ONSHORE NIAGARAN REEF PLAY (050)

The play consists of oil and gas accumulations trapped in areally restricted reefs in dolomite reservoirs of the Silurian Niagara Group that form an overall circular trend in the basin. This play is restricted to the southern, onshore portion of this trend and covers about 10,000 mi^2 (fig. 8). Reservoir rocks within the reefs are dolomitized and have both intercrystalline and vugular porosity averaging about eight percent. Most of the productive reefs are pinnacle reefs, each ranging from about 50 to 200 acres in area with 300 to 600 ft of relief. Pay thicknesses average about 70 ft, but vary greatly. Sealing is partially by Salina Group evaporites encasing the reefs. Depths to production range from about 2,000 to 6,000 ft.

The play produces an oil distinct from those in other Michigan basin accumulations. A strong phytane-over-pristane predominance and the lack of diasteranes indicates a carbonate source. Correlation of these oils and potential source rocks using carbon-isotope data shows that certain carbonate units in the Salina Group are the principal source rocks, with lesser contributions from part of the Niagaran reef rocks themselves. Generation could have begun as early as Devonian time.

Exploration history of the play consists of two main phases. The first phase began in the 1950's and was related to an extension of drilling from the Silurian reef trend in Ontario, Canada, into southeastern Michigan. The second phase began in the late 1960's was due primarily to improvements in seismic interpretation which allowed easier identification of reef prospects through thick, surficial glacial drift. A total of 1,100 reef fields have been discovered; about one-third of these fields are in this southern part of the reef trend. Most of the fields are small, less than 1 MMBO or 6 BCFG in size. Both oil and non-associated gas fields have been found. As of 1984, cumulative production for the entire Niagaran reef trend was about 280 MMBO and 1.6 TCFG. New field discoveries continue in the southern part of the overall Silurian reef trend, the area of this play. Large areas of the play remain undrilled, and the future potential for both oil and gas is very good.

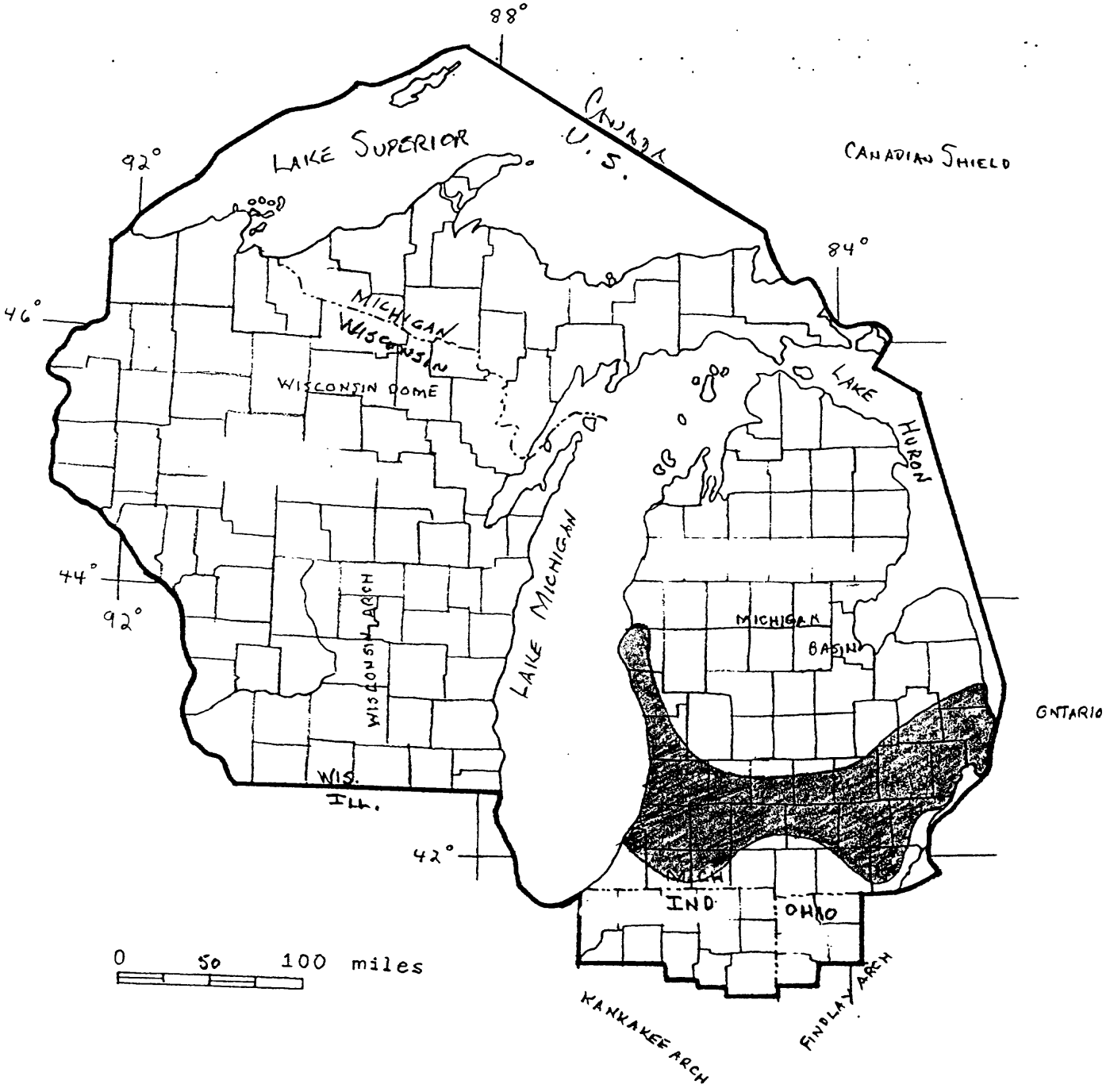

Figure 8. Map of Southern Onshore Niagaran Reef play.

OIL AND GAS PLAY DATA

PLAY **SOUTHERN ONSHORE NIAGARAN REEF**
PROVINCE **MICHIGAN BASIN** CODE **08-127-050**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0.4**
Gas	**0.6**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.1**	**1.4**	**2**	**3.4**	**9**	**27**
Gas (x 10^9 CFG)	**6**	**6.2**	**7.1**	**10**	**15**	**35**	**80**
Reservoir depth (x10^3 ft)							
Oil	**2**			**3.5**			**6**
Gas (non-associated)	**2**			**3.5**			**6**
Number of accumulations	**40**	**56**	**80**	**100**	**128**	**160**	**180**

Average ratio of associated-dissolved gas to oil (GOR)	**1600**	CFG/BBL
Average ratio of NGL to non-associated gas	**2**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

NORTHERN ONSHORE NIAGARAN REEF PLAY (060)

The play is characterized by oil and gas accumulations trapped in discrete reefs in dolomite reservoirs of the Silurian Niagara Group. The play area is a narrow northeast-southwest band covering about 4,000 mi^2 in the northern part of the overall circular trend of Silurian reefs (fig. 9). Reservoir rocks within the reefs are dolomitized and have both intercrystalline and vugular porosity averaging about eight percent. Most of the productive reefs are pinnacle reefs about 50 to 200 acres in area with 300 to 600 ft of relief. Pay thicknesses average about 70 ft, but vary greatly. These pinnacles are very numerous, especially in this northern onshore reef play area. Sealing is partially by Salina Group evaporites encasing the reefs. Depths to production range from about 3,000 to 7,000 ft.

The play produces an oil distinct from those in other Michigan basin accumulations. A strong phytane-over-pristane predominance and the lack of diasteranes indicates a carbonate source. Correlation of these oils and potential source rocks using carbon-isotope data shows that carbonate units in the Salina Group are the principal source rocks, with lesser contributions from part of the Niagaran reef rocks themselves. Trends in location of gas-filled versus oil-and-gas-filled reservoirs suggest differential migration from a basinward source. Generation and migration may have begun as early as the Devonian.

The exploration history of this play is similar to that of the previous discussed play (050). Of the 1,100 reef fields discovered in the basin, about two-thirds are located in this northern part of the circular reef trend. Although the play is densely drilled, discovery rates still remain high, and the future potential is estimated to be very good.

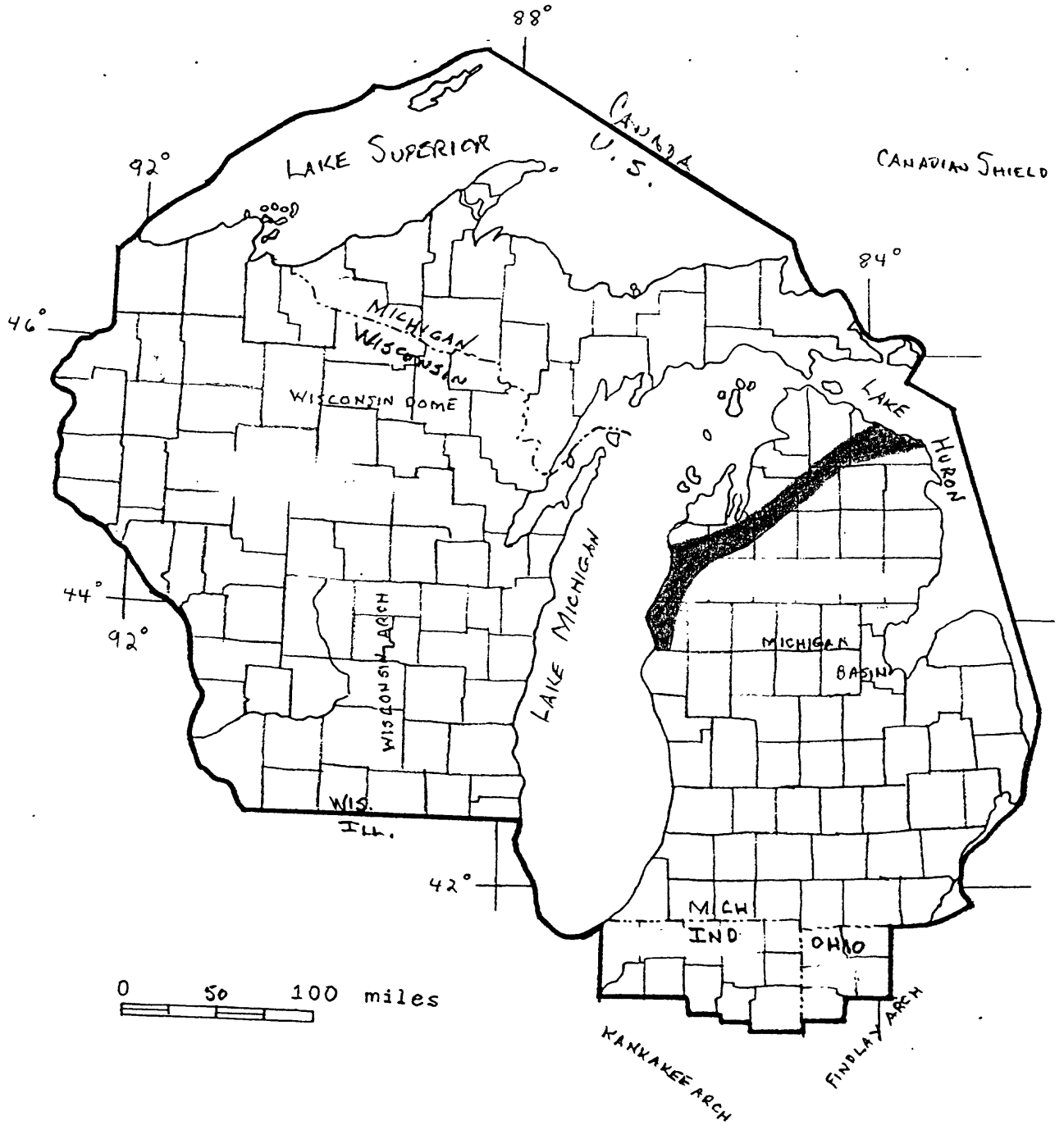

Figure 9. Map of Northern Onshore Niagaran Reef play.

OIL AND GAS PLAY DATA

PLAY **NORTHERN ONSHORE NIAGARAN REEF**
PROVINCE **MICHIGAN BASIN** CODE **08-127-060**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0.6**
Gas	**0.4**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.05**	**1.3**	**1.5**	**2.6**	**5**	**16**
Gas (x 10^9 CFG)	**6**	**6.1**	**6.7**	**8**	**12**	**30**	**80**
Reservoir depth (x10^3 ft)							
Oil	**3**			**4.5**			**7**
Gas (non-associated)	**3**			**4.5**			**7**
Number of accumulations	**20**	**24**	**32**	**40**	**50**	**66**	**80**

Average ratio of associated-dissolved gas to oil (GOR)	**1600**	CFG/BBL
Average ratio of NGL to non-associated gas	**4**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

OFFSHORE NIAGARAN REEF PLAY (070)

The play is speculative and consists of probable oil and gas accumulations trapped in discrete reefs in dolomite reservoirs of the Silurian Niagara Group. The play area covers about 5,000 mi^2, all of it in the offshore part of the arcuate Silurian reef trend in Lake Michigan and Lake Huron. Currently, all exploration is prohibited in this offshore area (fig. 10). Similar reservoir rocks within fields in the onshore part of the reef trend are dolomitized and have both intercrystalline and vugular porosity averaging about eight percent. Most of the accumulations are pinnacle reefs about 50 to 200 acres in area with 300 to 600 ft of relief. Pay thicknesses average about 70 ft. Sealing is partially by Salina Group evaporites encasing the reefs. Anticipated drilling depths in this play would range from about 2,000 to 7,000 ft.

Discovered fields in the onshore part of the Niagaran reef plays produce an oil distinct from those in other Michigan basin accumulations. A strong phytane-over-pristane predominance and the lack of diasteranes indicates a carbonate source. Correlation of these oils and potential source rocks using carbon-isotope data shows that certain Salina carbonate units are the principal source rocks, with lesser contributions from part of the Niagaran reef rocks themselves. Generation could have begun as early as Devonian time.

Discovered fields in the overall circular reef trend have, to date, been entirely from the onshore part of Michigan's Lower Peninsula. Offshore drilling is prohibited in Lakes Michigan and Huron; however, the reef trend undoubtedly extends offshore into the two lakes. A mix of oil and non-associated gas fields, similar to the two onshore reef plays, would also be expected. The future potential appears to be very good for both oil and gas, and field sizes would probably be similar to those alreadydiscovered onshore.

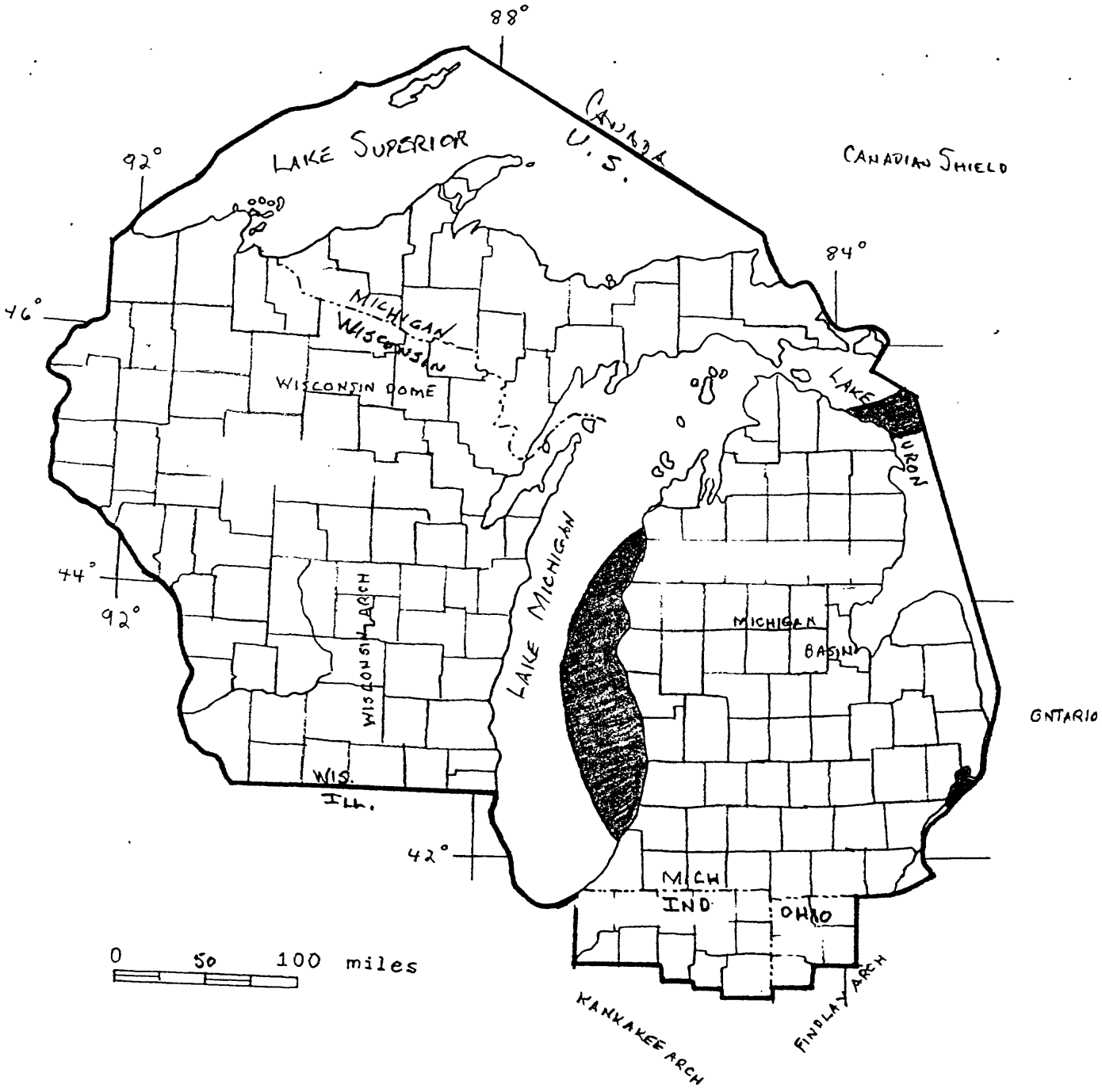

Figure 10. Map of Offshore Niagaran Reef play.

OIL AND GAS PLAY DATA

PLAY **OFFSHORE NIAGARAN REEF**
PROVINCE **MICHIGAN BASIN** CODE **08-127-070**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0.5**
Gas	**0.5**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.1**	**1.4**	**2**	**3.4**	**9**	**27**
Gas (x 10^9 CFG)	**6**	**6.2**	**7.1**	**10**	**15**	**35**	**80**
Reservoir depth (x10^3 ft)							
Oil	**2**			**4**			**7**
Gas (non-associated)	**2**			**4**			**7**
Number of accumulations	**40**	**56**	**80**	**100**	**132**	**168**	**200**

Average ratio of associated-dissolved gas to oil (GOR)	**1600**	CFG/BBL
Average ratio of NGL to non-associated gas	**3**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

PRAIRIE DU CHIEN PLAY (080)

The play is characterized by deep gas accumulations in structural-stratigraphic traps in sandstone reservoirs variously ascribed to the Ordovician Prairie du Chien Group, or the St. Peter Sandstone. The play area covers approximately 50,000 mi^2 (fig. 11). Sandstones in the Prairie du Chien extend over much of the central part of the basin and reach thicknesses of about 1,200 ft. Reservoir sandstones in the Prairie du Chien are silica-cemented, clean quartz sandstone with porosity of about ten percent. Lithologically, they are very similar to the St. Peter Sandstone, also Ordovician in age, but the precise correlation between the two is unresolved at present. The basic trapping mechanism is not completely understood, but seems to be a combination type. Although most discoveries have been deeper tests within producing Devonian anticlinal fields, porosity variation at least partially controls the trapping; porosity may be controlled in part by diagenetic interactions between the quartz grains and the associated clay assemblage. Producing depths range from about 7,800 ft to over 11,000 ft, the deepest production in the basin. The precise source rock is unknown, but a localized source in Ordovician rocks is suspected.

This play is the most recent of the major exploration plays in the Michigan basin, with the first gas discovery dating back to 1980. Since then, almost 20 non-associated gas fields have been discovered in Prairie du Chien reservoirs. Because of the recency of these discoveries, little is known of their actual size. Cumulative production as of 1984 was slightly over 5 BCFG. Because of very sparse drilling below the Devonian in the central part of the basin, an excellent potential exists for future gas discoveries. Porosity control by diagenesis, if favorable, could further increase the undiscovered gas potential by adding the possibility of off-structure stratigraphic traps.

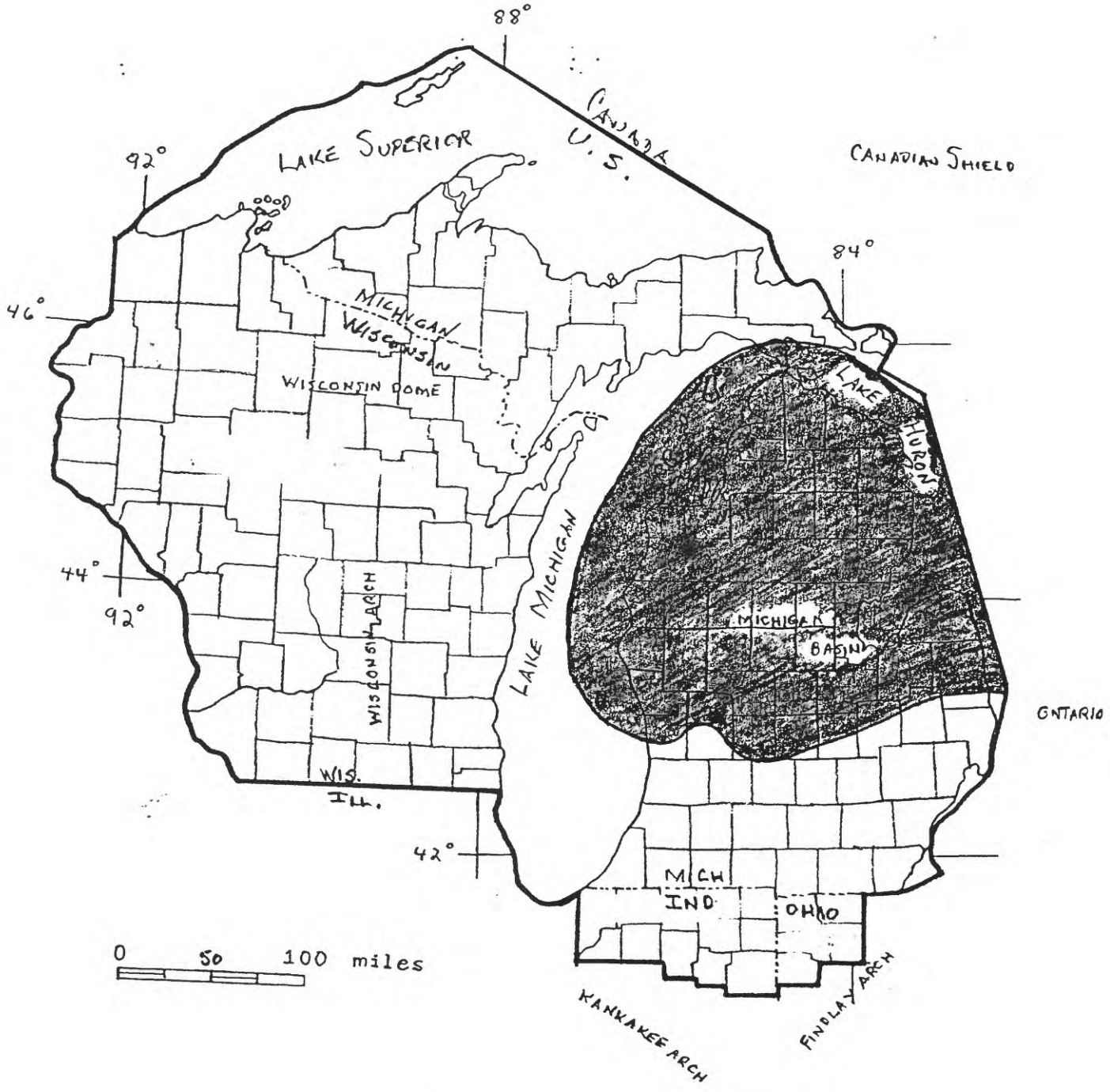

Figure 11. Map of Prairie du Chien play

OIL AND GAS PLAY DATA

PLAY **PRAIRIE DU CHIEN**
PROVINCE **MICHIGAN BASIN** CODE **08-127-080**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	
Other	
Hydrocarbon type	
Oil	**0**
Gas	**1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gas (x 10^9 CFG)	**6**	**7**	**10**	**20**	**50**	**175**	**300**
Reservoir depth (x10^3 ft)							
Oil	**0**			**0**			**0**
Gas (non-associated)	**7**			**10**			**12**
Number of accumulations	**10**	**16**	**24**	**30**	**38**	**52**	**60**

Average ratio of associated-dissolved gas to oil (GOR)	**0**	CFG/BBL
Average ratio of NGL to non-associated gas	**12.5**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

CAMBRIAN PLAY (090)

This play covers a broad area of 90,000 mi^2 in the Michigan basin, including offshore areas of Lakes Michigan and Huron. It is considered to be speculative, consisting of probable gas accumulations in stratigraphic, or possibly deep structural traps in Cambrian sandstone reservoirs (fig. 12). Total thickness of the Cambrian section is about 2,600 ft, and consists mainly of sandstone and minor dolomite in the Trempeleau and Munising Formations and Jacobsville Sandstone. Quality of reservoirs is relatively unknown, however, the apparent low densities of potential reservoir sandstones suggests adequate porosity. The Cambrian sequence outcrops in the Upper Peninsula of Michigan and in Wisconsin, and lies as deep as 17,000 ft in the center of the basin, therefore, there would be a wide range in drilling depths to reservoir objectives in the play.

Anticipated traps are thought to be stratigraphic, in the form of facies related porosity variations, unconformities, and possibly deep structural traps beneath shallower, established anticlinal trends. Hydrocarbon source rocks are hypothetical, but a conceivable source for gas may be in Ordovician rocks. No oil or gas discoveries have been made in the play and very few test wells have penetrated the Cambrian section in the overall Michigan basin. However, the future potential for gas is estimated to be good based on limited data available.

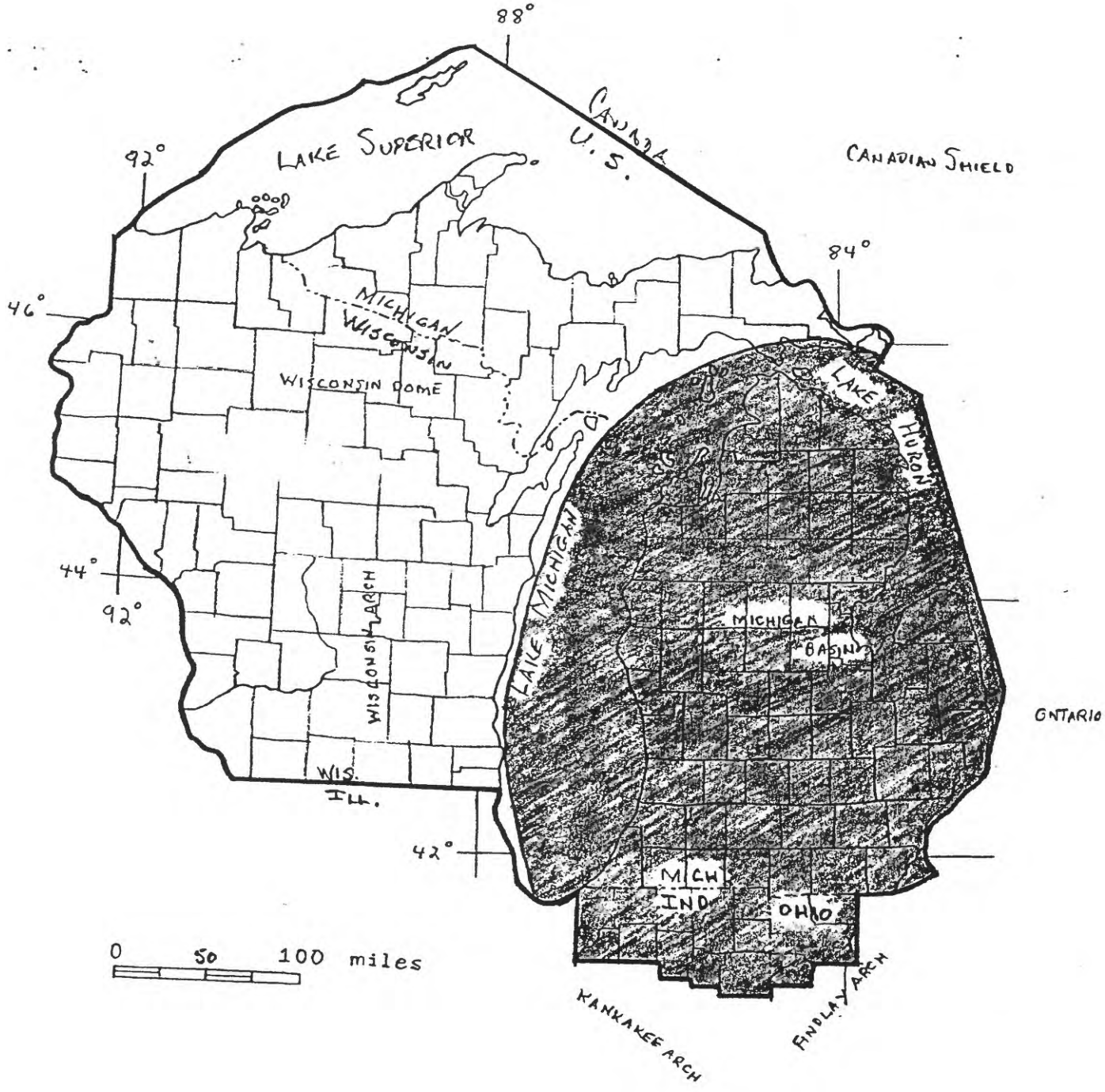

Figure 12. Map of Cambrian play.

OIL AND GAS PLAY DATA

PLAY **CAMBRIAN**
PROVINCE **MICHIGAN BASIN** CODE **08-127-090**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**0.50**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**0.50**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**0.90**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0**
Gas	**1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gas (x 10^9 CFG)	**300**	**600**	**900**	**1200**	**1800**	**3400**	**5000**
Reservoir depth (x10^3 ft)							
Oil	**0**			**0**			**0**
Gas (non-associated)	**8**			**11**			**13**
Number of accumulations	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Average ratio of associated-dissolved gas to oil (GOR)	**0**	CFG/BBL
Average ratio of NGL to non-associated gas	**12.5**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

ILLINOIS BASIN PROVINCE (128)

By Richard F. Mast

INTRODUCTION

The Illinois Basin province covers the State of Illinois and parts of the States of Indiana, Kentucky, Missouri, Tennessee, Arkansas and Mississippi. The northern part of the Mississippi Embayment is included as part of the Illinois Basin province. The province is bounded on its eastern flank by the Cincinnati Arch and Black Warrior basin, on the north by the Michigan basin, and on the west by the Ozark uplift and Iowa shelf. Sub-basins included within the province are the Fairfield basin, the Moorman syncline, and the Reelfoot basin. The Pascola arch is a major positive feature that lies within the Mississippi Embayment.

The province is approximately 550 mi long and 230 mi wide at the latitude of the Fairfield basin. It has a total area of approximately 101,600 mi^2 and is covered entirely by sedimentary rocks. The hydrocarbon prospective section in the Illinois basin part of the province includes Cambrian through Pennsylvanian age rocks. Depth to Precambrian basement in the central, deep part of the Illinois basin is greater than 13,000 ft. In the Mississippi Embayment the prospective section includes Cambrian through Mississippian age rocks, in addition to overlying Cretaceous and Tertiary rocks which may also be prospective (fig.13). About 4.2 BBO have been found in the Illinois basin since the advent of exploration in 1886, but little nonassociated gas. No commercial quantities of oil and gas have been found in the Mississippi Embayment part of the province. Five plays were defined and individually assessed: Post-New Albany (020); Silurian-Devonian Carbonate (030), Silurian Reef (040); Rough Creek Graben (050); and Mississippi Embayment (060).

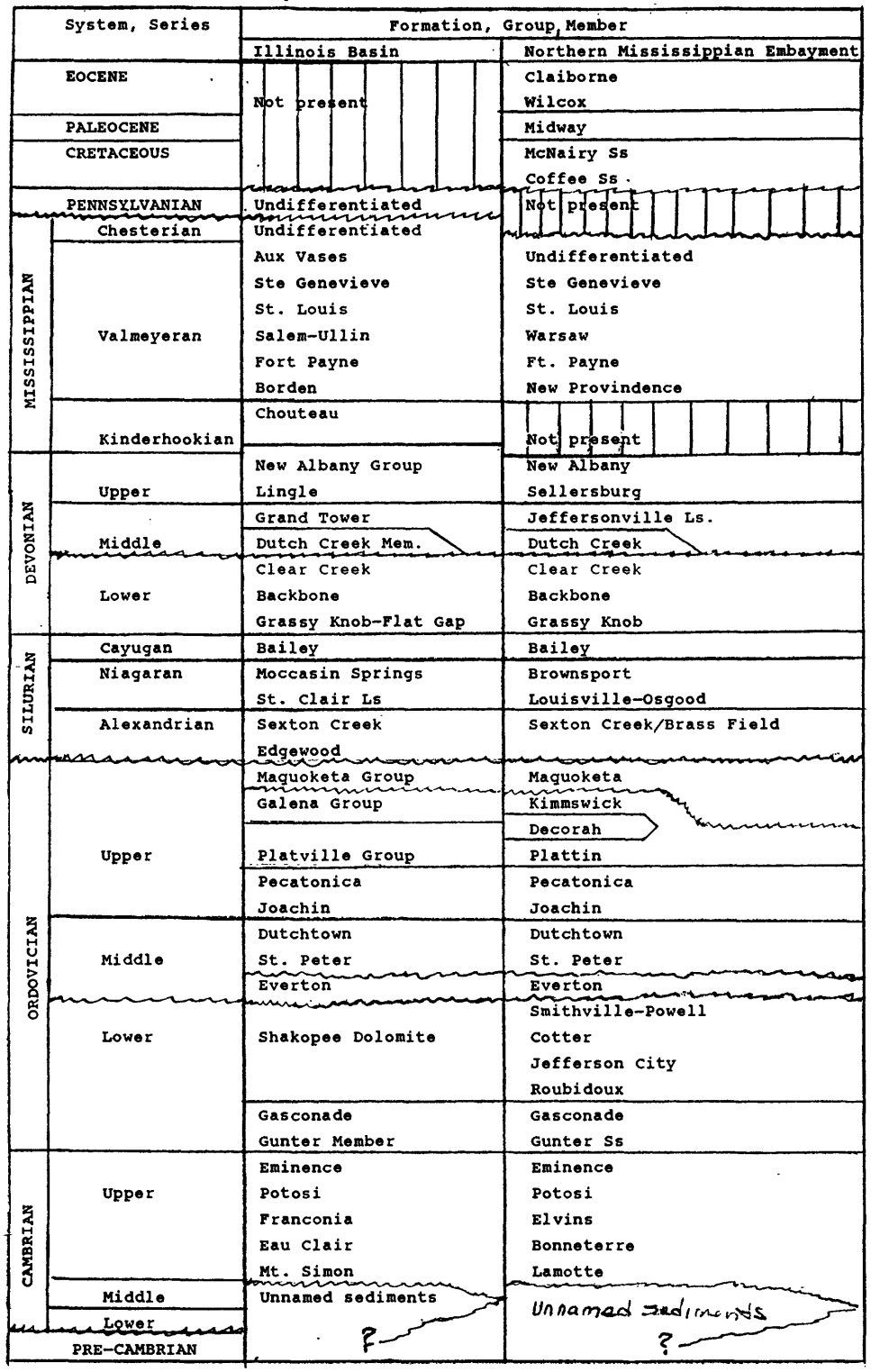

Figure 13. Generalized stratigraphic columns, Illinois Basin province.

POST-NEW ALBANY PLAY (020)

This extensively explored play, covering approximately 34,000 mi^2, involves oil accumulations principally in stratigraphic and structural combination traps in Mississippian and Pennsylvanian age sandstone and limestone reservoirs overlying shale source rocks in the Upper Devonian New Albany Group. In Illinois, the play is bounded on the south by the Rough Creek fault zone and the mineralized area of southern Illinois and Kentucky. In Kentucky, production in the play is found south of the Rough Creek fault zone. The north, east, and west boundaries are less definitive because of extensive vertical and horizontal migration of oil from source rocks in the New Albany Shale (fig.14)

Reservoirs are both sandstone and limestone. Sandstones are concentrated in the Mississippian Chesterian Series and Lower Pennsylvanian part of the section (fig. 14). Sandstone reservoirs are moderately thin with oil columns averaging about 22 ft with generally excellent reservoir properties. Limestone reservoirs occur mainly in the lower part of the Mississippian in the Valmeyeran series (Salem, St. Louis, St. Genevieve, etc.) and are also thin, with an average oil column of 11 ft. Reservoirs of the St. Genevieve, St. Louis and Salem Limestones are oolitic and have fair to excellent reservoir characteristics.

Source rocks are organic-rich shales in the underlying Devonian-Mississippian New Albany Group. Geochemical studies show that these shales are mature over a wide area of Illinois, Indiana and Kentucky. There is little evidence that indicates other shales in the Mississippian-Pennsylvanian section have generated hydrocarbons. Seals are of local rather than regional extent which allows oil generated in the New Albany to migrate upward into younger stratigraphic units. Lateral updip migration of oil is indicated by the presence of accumulations in the play outside of the area in which New Albany shales are thermally mature. These shales generated hydrocarbons during late Paleozoic and early Mesozoic time, after most of the traps in the play were formed.

Traps are mainly combination types which range from almost pure structural traps, like that at the Salem Consolidated field, to almost pure stratigraphic traps in the Eldorado Consolidated Field. Fields range in size from a few thousand barrels to over 400 MMBO. Drilling depths to objectives range from less than 500 to over 4,000 ft.

About 4 billion barrels (> 95 percent) of the oil discovered in the Illinois basin province has been found in rocks of this play. The largest accumulations are the Salem and Louden fields, both with ultimate recoveries of slightly more than 400 MMBO. Although the play is in a very mature stage of exploration, a modest future potential still exists for additional new discoveries chiefly in stratigraphic or unconformity traps.

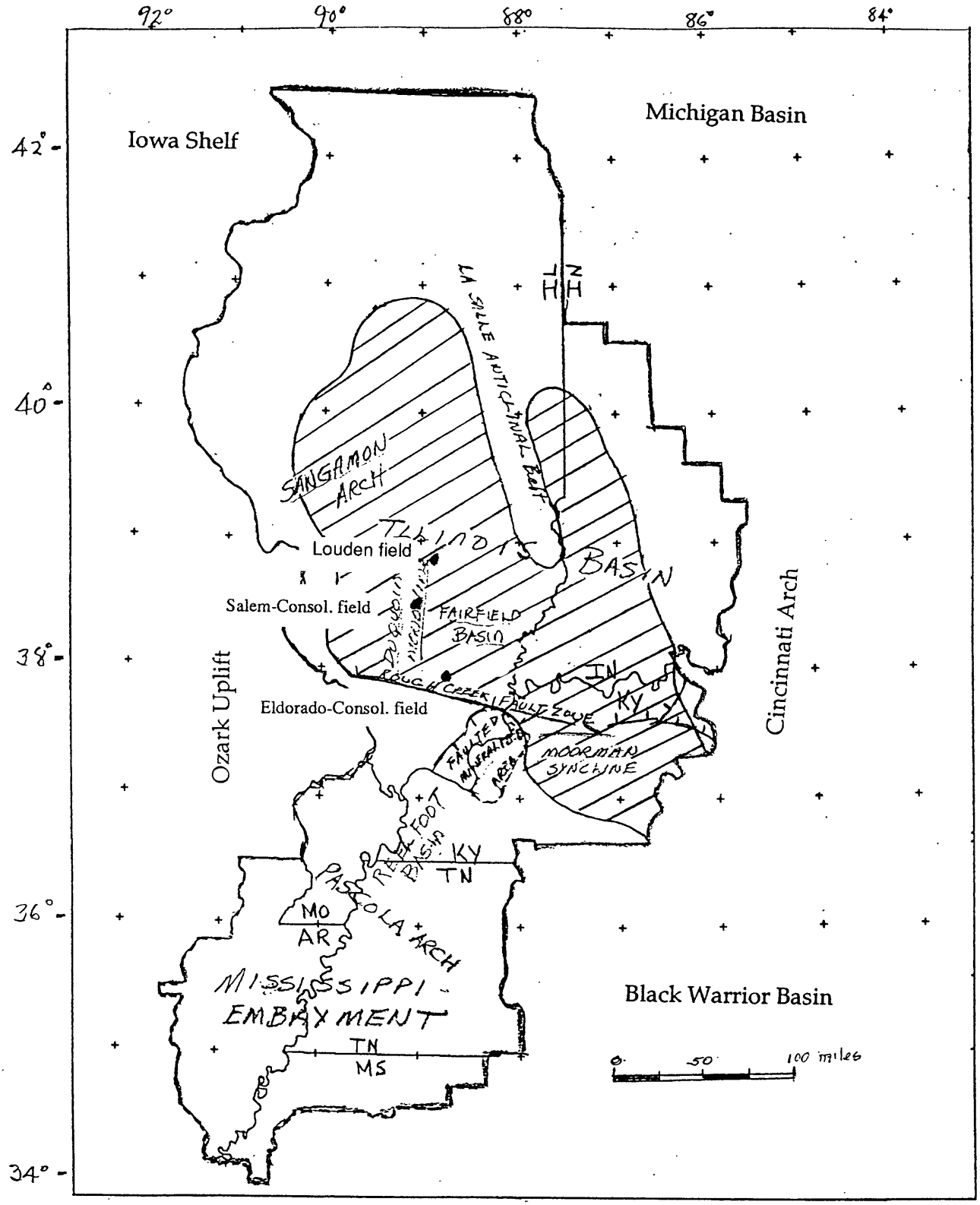

Figure 14. Map of Post-New Albany play.

OIL AND GAS PLAY DATA

PLAY **POST NEW ALBANY**
PROVINCE **ILLINOIS BASIN** CODE **08-128-020**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.04**	**1.2**	**1.5**	**2**	**3.4**	**5**
Gas (x 10^9 CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth (x10^3 ft)							
Oil	**1**			**2.5**			**4.5**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**5**	**7**	**11**	**15**	**20**	**28**	**40**

Average ratio of associated-dissolved gas to oil (GOR)	**1000**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

SILURIAN-DEVONIAN CARBONATE PLAY (030)

This play, covering 29,300 mi^2, is characterized by oil accumulations in combination traps in Silurian and Devonian age carbonate reservoirs which underlie New Albany Group source rocks. The play is bounded on the south in Illinois by the Rough Creek fault zone and the faulted mineralized area. However, the area south of the Rough Creek fault zone and east of the mineralized area in Kentucky is both a productive and prospective part of the play (fig.15).

Reservoirs are predominantly dolomite, limestone, and sandstone. Reservoir thicknesses, permeabilities and porosities are highly variable. A few excellent sandstone reservoirs are found in the Dutch Creek Member of the Middle Devonian Grand Tower Limestone. Source rocks are principally organic-rich shales in the overlying Devonian-Mississippian New Albany Group. Some of the oil could also be locally derived from shaley carbonate source rocks within the play and from shale in the underlying Upper Ordovician Maquoketa Group. Occurrences of New Albany type oil, particularly in the Dutch Creek Member a few hundred feet below the local base of the New Albany, suggests some downward migration of New Albany generated oil. Lateral, updip migration of oil is indicated by the presence of New Albany type oil in the play outside of the area in which New Albany shales are know to be mature. Lateral migration pathways are difficult to identify, and in some areas movement of oil may have had to occur through fractures in low permeability carbonate rocks. Hydrocarbons were generated during late Paleozoic and early Mesozoic time after most of the traps in the play were formed.

A wide variety of trap types occur in the play ranging from nearly pure structural traps, such as the Centralia field, to unconformity traps at the Mt. Auburn Consolidated field. Discovered fields are small in size, usually less than 5 MMBO. Drilling depths to reservoir targets range from 500 ft to over 5,300 ft.

Approximately 150 to 200 million barrels (4 percent) of the recoverable oil discovered in the Illinois basin has occurred in this play and some modest potential still remains for new discoveries in stratigraphic and unconformity traps. The play is well explored in its northern half and along the margins, and moderate to low amounts of exploration drilling have been done in the Fairfield basin area. The future potential for undiscovered resources in the play appears to be limited, however, by the lack of good quality reservoirs and the absence of adequate seals in the prospective section below the base of the New Albany Group.

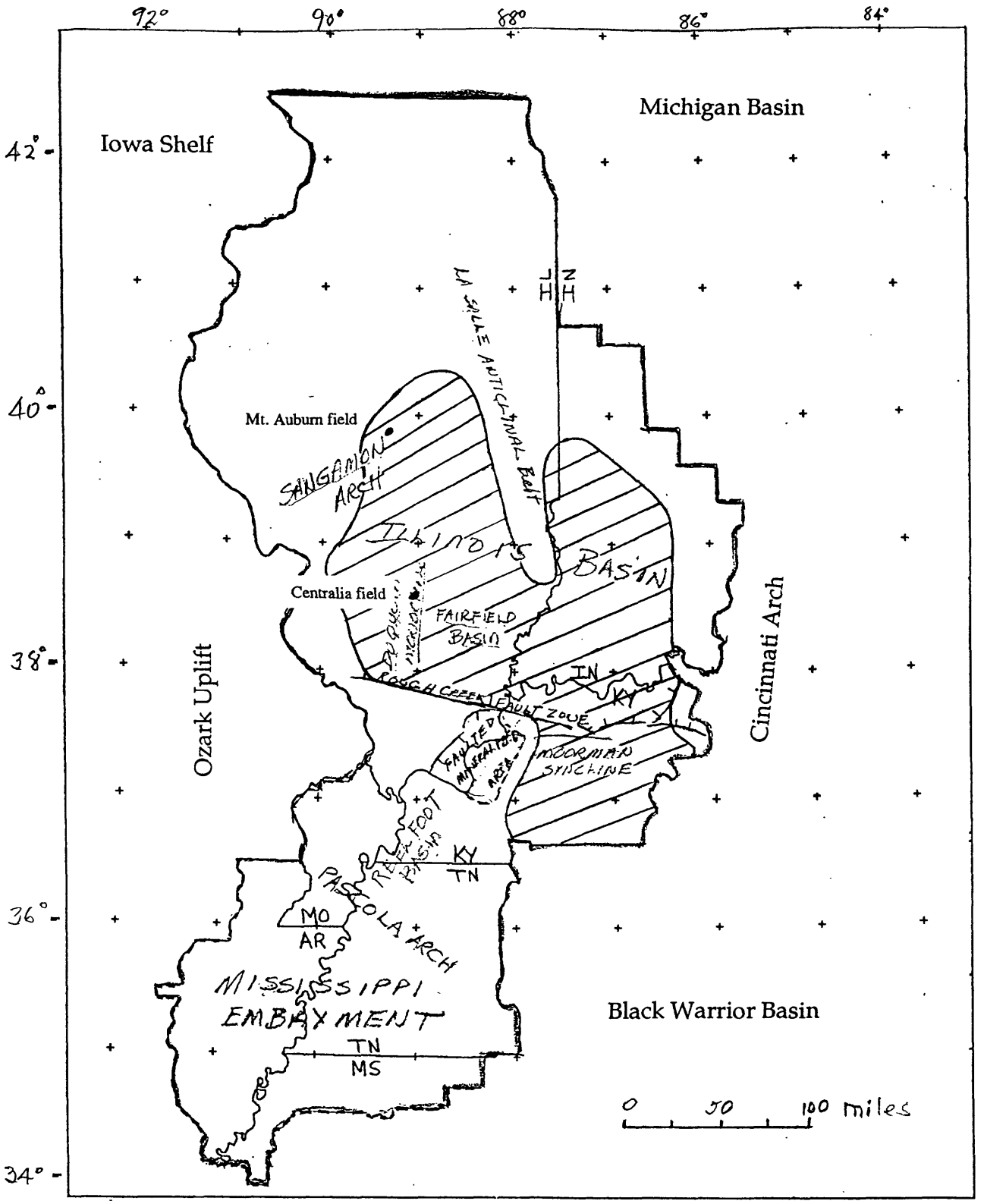

Figure 15. Map of Silurian-Devonian Carbonate play.

OIL AND GAS PLAY DATA

PLAY **SILURIAN-DEVONIAN CARBONATE**
PROVINCE **ILLINOIS BASIN** CODE **08-128-030**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.03**	**1.2**	**1.5**	**2.2**	**5**	**15**
Gas (x 10^9 CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth (x10^3 ft)							
Oil	**0.5**			**1.5**			**6**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**10**	**12**	**16**	**20**	**15**	**33**	**40**

Average ratio of associated-dissolved gas to oil (GOR)	**1000**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

SILURIAN REEF PLAY (040)

The play covers approximately 35,300 mi^2 and consists of oil accumulations in pinnacle reef carbonate reservoirs, or in younger reservoirs that are draped over reefs, both with a common oil source in the New Albany Group. The play includes the area of pinnacle and interstratal reef limestone occurrences that are overlain by shale in the New Albany (fig. 16). Reef limestone reservoirs are primarily of Silurian and secondarily of Devonian age, and in many instances the overlying draped Devonian limestones also form part of the total reservoir sequence below the New Albany. Areal extent and thicknesses of oil-bearing reservoirs vary widely, and reservoir quality ranges from fair to excellent.

Most, if not all, of the pinnacle reef accumulations in the play contain New Albany type oil. Since the productive reefs lie mostly on the basin shelves, the thickness of the interval between the source shales and the underlying reservoirs is very thin, which allows for downward migration. In many cases, shales in the New Albany are part of the draped sequence and form at least a part of the trap. Hydrocarbons in the play were generated during the late Paleozoic and Mesozoic.

Fields are small, generally less than 5 MMBO in size. The largest accumulation in the play is the Marine field, which has an estimated size of more than 12 MMBO. Depth to production is fairly shallow ranging from about 1,000 to 2,500 ft.

Approximately 30 to 40 million barrels (< 1 percent) of the recoverable oil discovered in the Illinois basin has been found in Silurian pinnacle reefs of this play, or in drape structures over these features in both southwestern and eastern Illinois, and in interstratal reefs on the northern shelf of the basin. Exploration of these reefs is well advanced because overlying strata are usually draped over reef build-ups and seismic reflections from the overlying Devonian limestones easily define these features. Interstratal reefs cannot be detected so easily and, therefore, are more likely targets for future exploration, however, the future potential is low. The deep Fairfield basin is excluded from the play because it is not considered prospective for two reasons: (1) occurrences of similar reservoir rocks are considered unlikely, and (2) the vertical distance between New Albany source rocks and potential reservoirs is too great to allow for downward migration of oil from source shales of the New Albany.

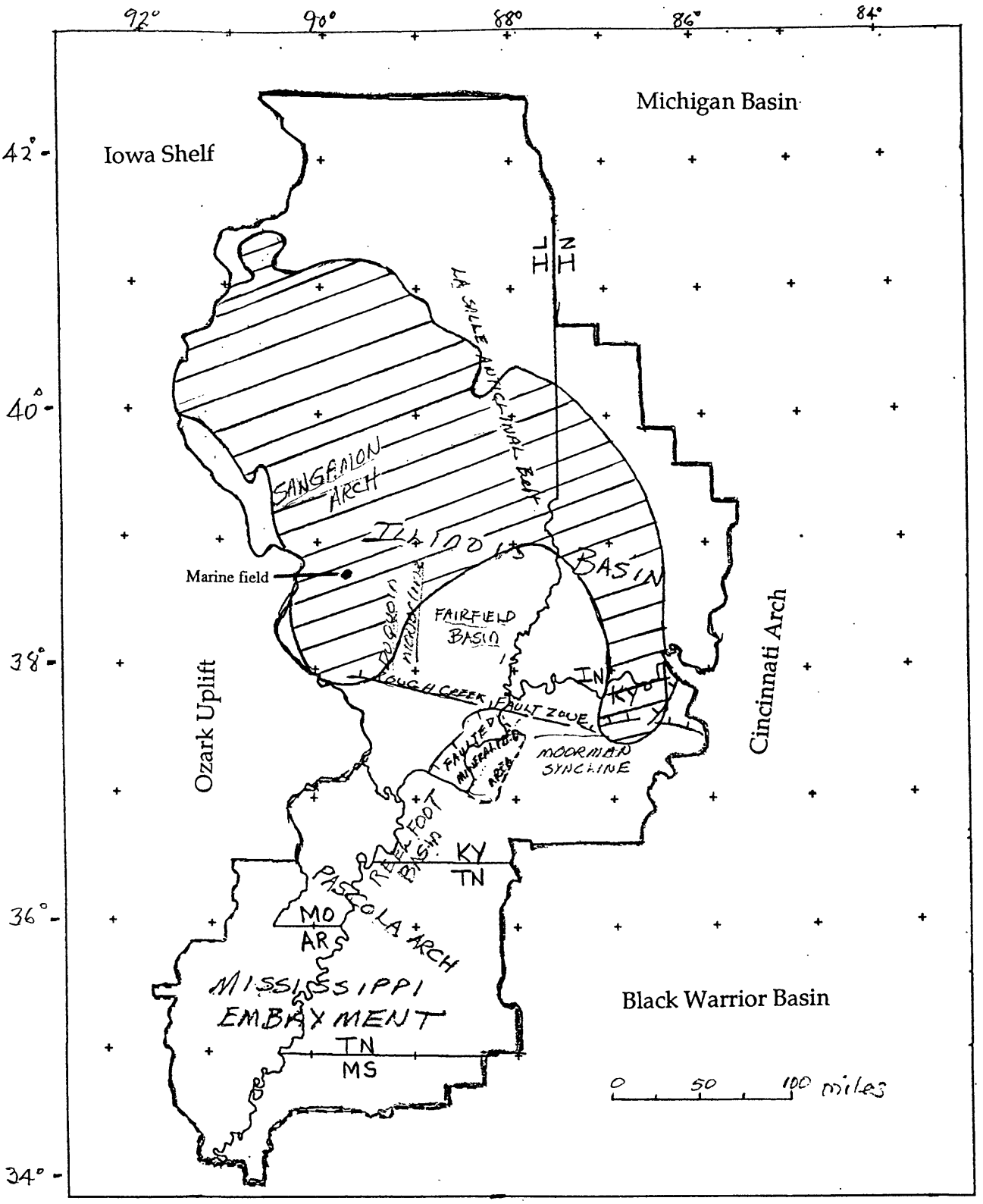

Figure 16. Map of Silurian Reef play.

OIL AND GAS PLAY DATA

PLAY **SILURIAN REEF**
PROVINCE **ILLINOIS BASIN** CODE **08-128-040**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.03**	**1.2**	**1.4**	**1.8**	**3**	**5**
Gas (x 10^9 CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth (x10^3 ft)							
Oil	**0.5**			**1**			**4**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**5**	**6**	**8**	**10**	**14**	**22**	**30**

Average ratio of associated-dissolved gas to oil (GOR)	**1000**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

ROUGH CREEK GRABEN PLAY(050)

The play, which covers an area of about 50,200 mi^2, is speculative and is characterized principally by fault and fault-related structural traps in Cambrian clastic reservoirs with a common source in the Cambrian Eau Clair Shale. The main target area is the northward extension of the Reelfoot rift, the Rough Creek graben. However, the play area is drawn larger than the local area of the Rough Creek graben in order to include any generated but untrapped hydrocarbons that would have migrated northward, and possibly up the stratigraphic section, toward the basin margin (fig. 17).

The principal reservoir is the Cambrian Mt. Simon Sandstone, which underlies the Eau Clair Shale. The Mt. Simon, where penetrated in major fields in the basin, has displayed generally poor reservoir properties. However, early accumulation of hydrocarbons might have helped to preserve adequate reservoir properties. Dolomite reservoirs may also occur in Upper Cambrian and Lower Ordovician carbonate units overlying the Eau Clair Shale.

Shales in the Eau Clair and equivalents are the most likely source for hydrocarbons in the play. However, based on the few analyses available for this unit, the average organic carbon content is quite low, generally in the range of 0.1-0.3 percent. Also, the little known section below the Mt. Simon might contain organic-rich lacustrine facies in early graben sediments that could have been a source of hydrocarbons. Hydrocarbon generation would probably have started by the Late Ordovician or Early Silurian, a time prior to the formation of trapping structures in the basin, but after many of the structures in the graben formed. Shales in the Eau Clair should provide adequate seals for the underlying sandstone reservoirs, but only local seals are anticipated to be present in the carbonate reservoir section overlying the Eau Clair. The Ordovician St. Peter Sandstone could have provided a migration pathway for hydrocarbons northward and up section from the graben into younger Ordovician carbonate reservoirs.

Many bounding faults and fault-related structures in the Rough Creek graben are large. However, potential trap sizes in the overlying carbonates are expected to be smaller. Drilling depths to the majority of graben targets are about 12,000 ft, and in some areas would exceed 20,000 ft. These depths suggest that this is principally a gas play.

No commercial hydrocarbons have been found in either the St. Peter Sandstone or older rocks of the Illinois basin, and only a few oil shows have been reported in this section. Both the graben and Reelfoot rift areas of the play are very lightly explored. However, basement rocks have been penetrated on most of the major structures north of the Rough Creek fault zone, but without positive evidence of hydrocarbons. The future potential for gas is considered to be minimal.

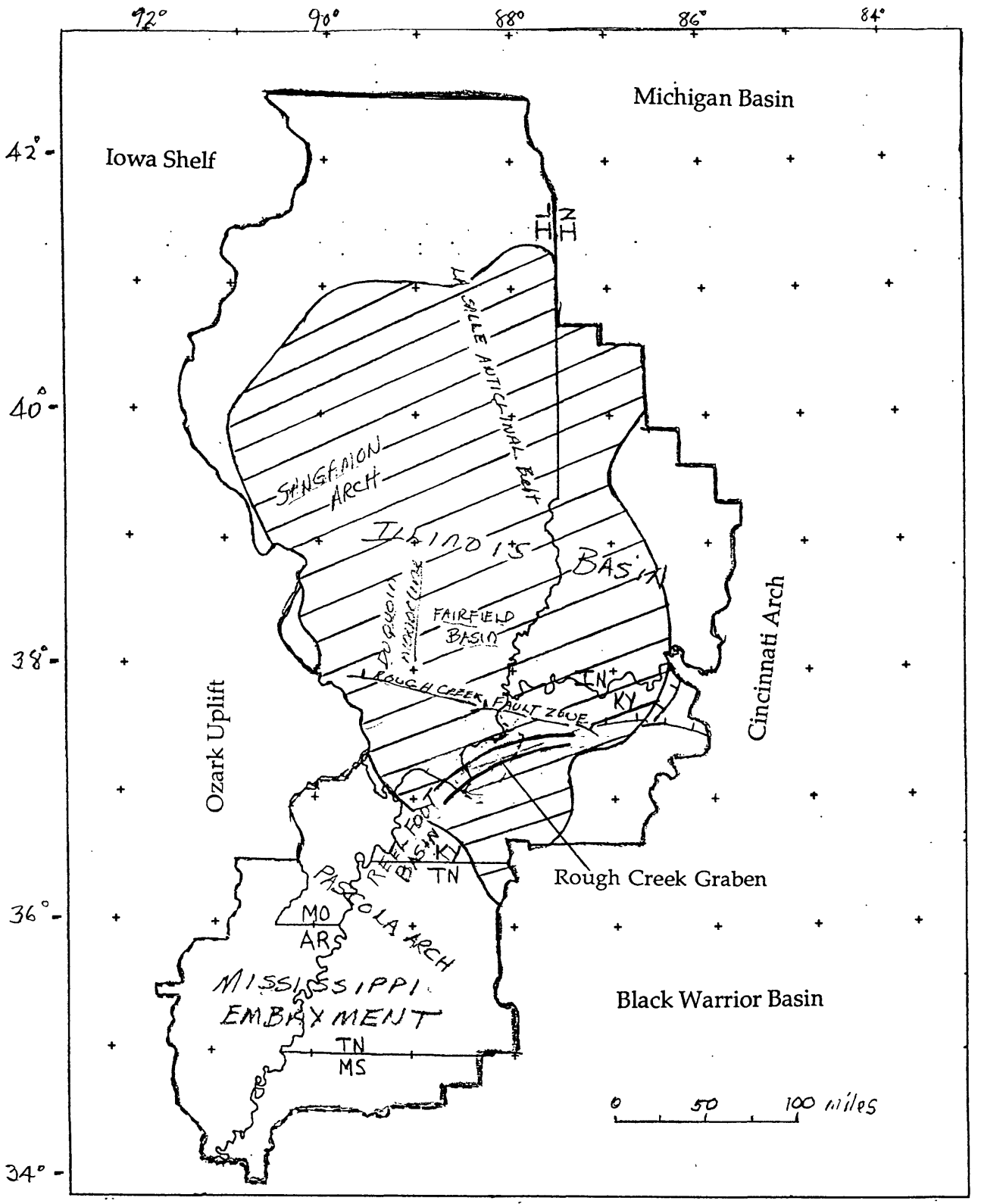

Figure 17. Map of Rough Creek Graben play.

OIL AND GAS PLAY DATA

PLAY **ROUGH CREEK GRABEN**
PROVINCE **ILLINOIS BASIN** CODE **08-128-050**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**0.20**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**0.20**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**0.50**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0**
Gas	**1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gas (x 10^9 CFG)	**100**	**200**	**350**	**500**	**750**	**1250**	**2500**
Reservoir depth (x10^3 ft)							
Oil	**0**			**0**			**0**
Gas (non-associated)	**3**			**8**			**12**
Number of accumulations	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Average ratio of associated-dissolved gas to oil (GOR)	**0**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

MISSISSIPPI EMBAYMENT PLAY (060)

This speculative gas play covers an area of about 26,200 mi^2 and consists of fault and fault-related structural traps in clastic reservoirs with Cambrian marine shales as a hydrocarbon source (fig. 18). The play is the southward extension of the Rough Creek Graben play except that the Upper Ordovician Maquoketa Shale is absent over most of the play as a result of widespread truncation on the Pascola arch. Because the Maquoketa is absent as a regional seal, hydrocarbons generated from pre-Maquoketa source rocks are able to leak upward into the overlying Cretaceous sediments in the Mississippi Embayment.

Principal clastic reservoirs are the Cambrian Lamotte Sandstone and sandstones in the Lower Ordovician Roubidoux and Gunter. Carbonate rocks may be good reservoirs directly below the pre-Cretaceous unconformity and reservoirs might also occur in the Upper Cambrian and Lower Ordovician dolomite section.

Principal source rocks are shales in the Cambrian Bonneterre which are generally equivalent to the Eau Clair of the Illinois basin. Available geochemical data indicates that the organic content of these shales is usually quite low. However, pre-Lamotte rocks may contain lacustrine beds in the earlier Cambrian Reelfoot rift sediments that might also have been a source of hydrocarbons. Generation and migration of gas would have occurred prior to uplift of the Pascola arch.

A variety of trap-types can be anticipated in the play, however, fault and fault-related structures associated with the development of both the Reelfoot rift and Pascola arch would be the principal traps. In addition, unconformity and stratigraphic traps might also be possible exploration targets. A limiting factor in trapping hydrocarbons is the overall lack of adequate seals in the section, with the possible exception of shales in the Bonneterre.

Exploration has been light and only a few deep tests have been drilled, and although shows have been reported, no commercial amounts of hydrocarbons have been found in the Mississippi Embayment play. The potential for the discovery of future gas resources is low.

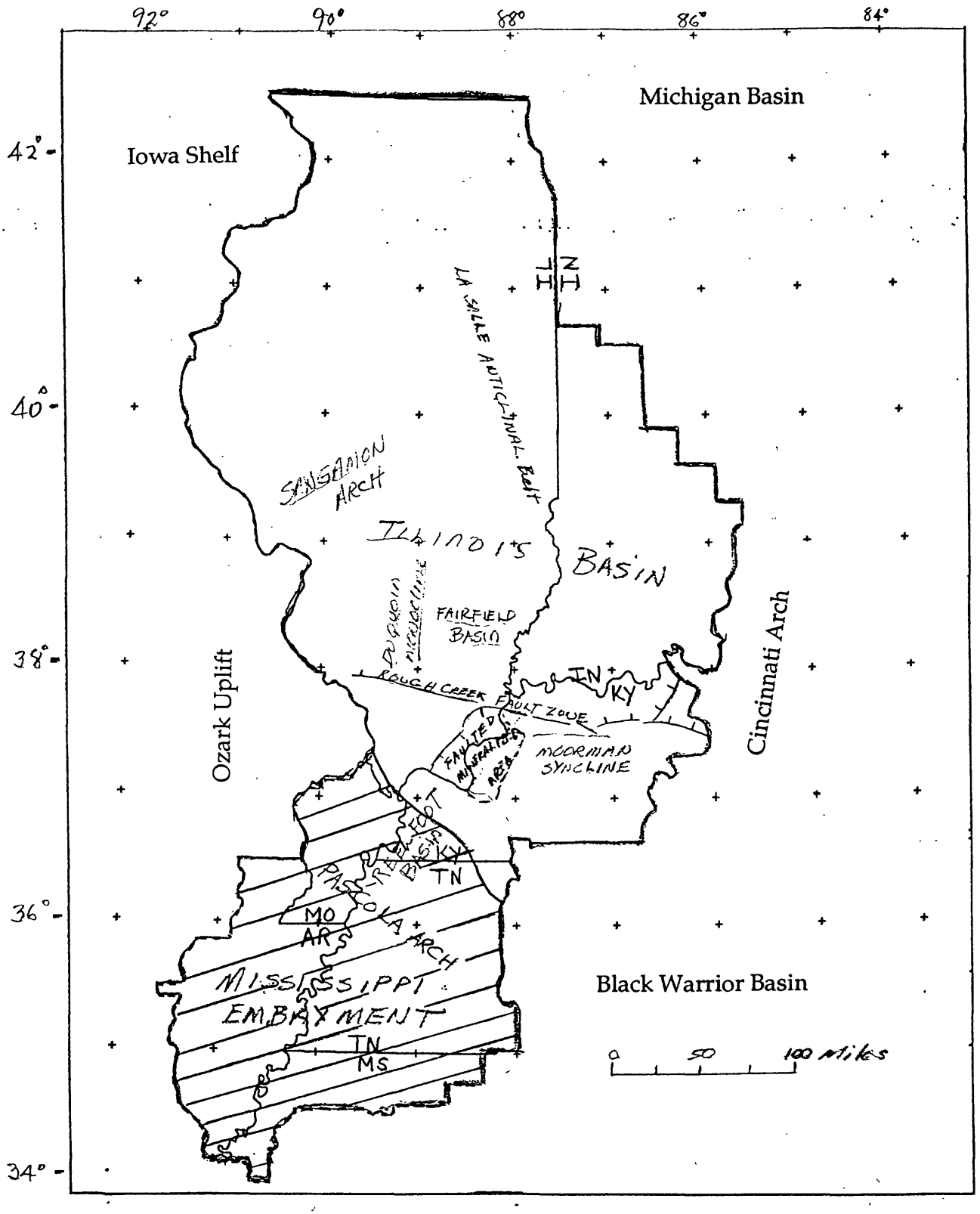

Figure 18. Map of Mississippi Embayment play.

OIL AND GAS PLAY DATA

PLAY **MISSISSIPPI EMBAYMENT**
PROVINCE **ILLINOIS BASIN** CODE **08-128-060**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**0.90**
Timing (T)	**0.30**
Migration (M)	**0.50**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**0.14**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**0.80**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0**
Gas	**1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gas (x 10^9 CFG)	**100**	**150**	**225**	**300**	**450**	**1000**	**1500**
Reservoir depth (x10^3 ft)							
Oil	**0**			**0**			**0**
Gas (non-associated)	**1.5**			**5**			**20**
Number of accumulations	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Average ratio of associated-dissolved gas to oil (GOR)	**0**	CFG/BBL
Average ratio of NGL to non-associated gas	**1**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

CINCINNATI ARCH PROVINCE (129)

By Robert T. Ryder

INTRODUCTION

The U.S.A. part of the Cincinnati Arch province is a 500-mi-long by 100 to 250-mi-wide tectonic arch that extends from western Ohio and north-central Indiana, through central Kentucky and central Tennessee, to northwestern Alabama, and covers an area of about 63,000 mi^2. The arch is flanked on the west by the Illinois basin and Mississippi embayment, and on the east by the Appalachian basin. The northern and southern ends of the arch are bounded by the Michigan basin and Black Warrior basin, respectively. The southern and central parts of the Cincinnati arch are subdivided into three structural elements: the Nashville dome in central Tennessee; the Lexington dome in north-central Kentucky; and the intervening Cumberland saddle. North of Cincinnati, Ohio the arch bifurcates into an eastern positive element, the Findlay arch, and a western positive element, the Kankakee arch.

The province contains a Paleozoic sedimentary rock section that ranges in thickness from less than 3,000 ft on the crests of prominent surface domes to more than 7,500 ft on the western flank of Nashville Dome (fig. 19). Oil and gas production was first established at shallow depths in Middle and Upper Ordovician carbonate reservoirs as early as the 1820's and 1860's in the province. The Unconformity (020) and Trenton (030) plays were individually assessed in the province; other, less significant plays were assessed in the aggregate.

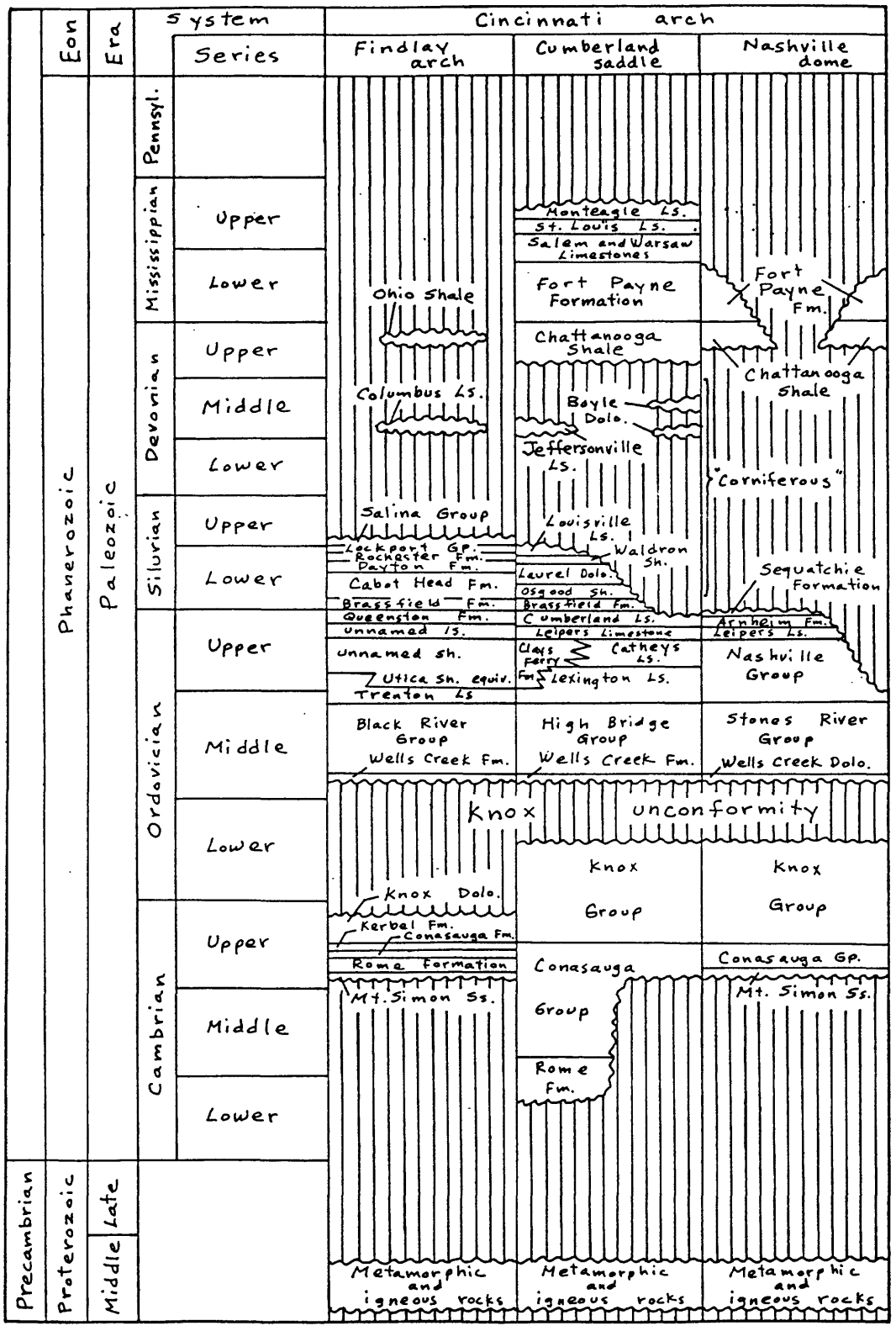

Figure 19. Generalized stratigraphic columns, Cincinnati Arch province.

UNCONFORMITY PLAY (020)

This play derives its name from, and is characterized by, oil accumulations in sub-Knox unconformity dolomite reservoirs in the Cumberland saddle and in the Morrow County, Ohio part of the Appalachian basin province (131) (fig. 20); these accumulations are stratigraphically trapped in erosional remnants (buried hills) of karstic origin. The dolomite reservoirs are Late Cambrian to Early Ordovician in age, whereas the overlying seals are early Middle Ordovician in age. The play extends across the entire Cincinnati Arch province (approximately 63,000 mi^2).

Vuggy dolomite in the Knox Group (Dolomite) is the primary reservoir in the play (fig. 19). In Morrow County, Ohio, the reservoir consists of medium to coarsely crystalline, vuggy dolomite with 15 percent average porosity and 100 millidarcies average permeability. Commonly, the porosity and permeability of these reservoirs are enhanced by solution-enlarged fractures and caverns. Oil saturated zones as thick as 110 ft are present in the buried hills. The Knox Group reservoirs in the Cumberland saddle oil fields are more finely crystalline than the Morrow County reservoirs. As many as four 30- to 40-ft-thick, finely crystalline dolomite reservoirs are recognized in the Knox Group in the Cumberland saddle. The porosity of these reservoirs ranges from 6.4 to 14.2 percent and the permeability ranges from 0.7 to 1.7 millidarcies. These low permeability values suggest that some of the reservoirs require tectonic fracturing to be oil productive.

Oil is the dominant type of hydrocarbon in the play. The most likely source for oil in the Findlay arch-Kankakee arch part of the play is the Upper Ordovician Utica Shale and equivalents (fig. 19). Total organic carbon (TOC) values for this black shale sequence in eastern Ohio and adjoining Pennsylvania range from 1 to 3 weight percent. The stratigraphic position and immaturity of the Utica Shale in the province require that Utica-generated oil migrate downsection about 700 ft and laterally at least 100 mi from the Appalachian basin to accumulate in Knox reservoirs. The Upper Devonian Chattanooga Shale is the most likely source for oil in the Cumberland saddle-Lexington dome-Nashville dome part of the play (fig. 19). The Chattanooga Shale is organic-rich and in the Nashville dome area has an average TOC of about 16 weight percent. As in the case of the Utica source, downsection migration and probable long-distance migration is required for Chattanooga-derived oil to accumulate in Knox reservoirs. Time-temperature plots suggest that oil was generated from the Utica and Chattanooga Shales in late Paleozoic time and, therefore, the majority of the permeability barriers and structures in the Knox Group were available to trap the migrating oil.

Erosional remnants of porous dolomite in the Knox Group, unconformably overlain by impermeable shale and carbonate of the Middle Ordovician Wells Creek Formation, provide the majority of traps for the play. Numerous exploratory holes have been drilled in the Cumberland saddle part of the play where the depth to the Knox unconformity ranges from 1,500 to 3,000 ft. Exploratory holes to the Knox unconformity are less common on the Findlay arch where the depth to the unconformity ranges from 1,700 to 2,400 ft, and sparse in the Kankakee arch, Lexington dome, and Nashville dome where the depth to the unconformity is 1,500 ft or less. The first commercial oil in the play was discovered in the Cumberland saddle and Findlay arch in the early 1900's. To 1987, approximately 43 small Knox oil fields have been discovered in the province (1 on the Kankakee arch, 1 on the Findlay arch, and 41 in the Cumberland saddle). The future potential for undiscovered Knox oil is estimated to be fair in the Cumberland saddle part of the play.

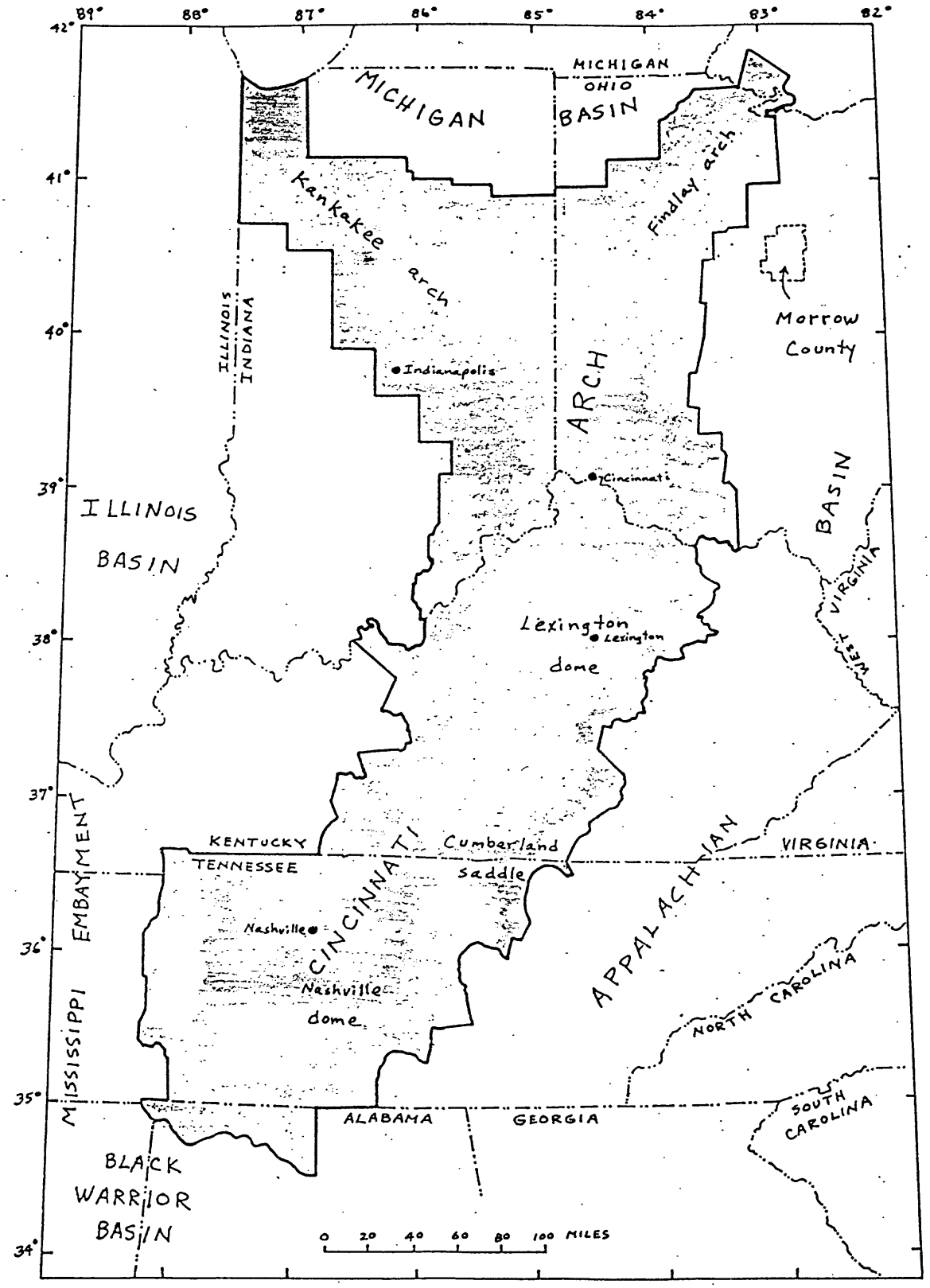

Figure 20. Map of Unconformity play.

OIL AND GAS PLAY DATA

PLAY **UNCONFORMITY**
PROVINCE **CINCINNATI ARCH** CODE **08-129-020**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.01**	**1.1**	**1.2**	**1.5**	**2.5**	**5**
Gas (x 10^9 CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth (x10^3 ft)							
Oil	**1**			**2**			**4**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**5**	**6**	**7**	**8**	**10**	**14**	**20**

Average ratio of associated-dissolved gas to oil (GOR)	**200**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

TRENTON PLAY (030)

This play derives its characteristics from the giant Lima-Indiana field on the Findlay and Kankakee arches that produces oil and gas from the Middle and Upper Ordovician Trenton Limestone (fig. 21). The major type of trap in the Lima-Indiana field, and in this play, is a stratigraphic trap where porous dolomite pinches out updip into nonporous limestone. Structural traps, such as anticlines and structural terraces, and other stratigraphic traps caused by porous bioclastic limestone pinching out into impervious limestone are locally important. In addition to the Trenton Limestone, the Lexington Limestone, Catheys Limestone, Leipers Limestone, Nashville Group, Black River Group, High Bridge Group, and Stones River Group (fig. 19) are also prospective in the play. Except for the center of the Lexington and Nashville domes, where uppermost Middle Ordovician strata are exposed, the play covers the entire Cincinnati arch province (approximately 63,000 sq mi).

Facies-controlled and fault- and fracture-controlled vuggy dolomite are the primary reservoirs in the play. The facies-controlled dolomite reservoirs range from 50-ft-thick, widespread, tabular-shaped units to local, 10- to 30-ft thick, lens-shaped units. The fault- and fracture-controlled dolomite reservoirs are subvertical tabular-shaped bodies as much as one mile across. The permeability of the vuggy dolomite reservoirs locally attain several darcies owing to the presence of large vugs and cavities. Bioclastic limestone is an important secondary reservoir in the play. These reservoirs were deposited as beach ridges and elongate, discontinuous mollusk buildups that range in thickness from 5 to 35 ft.

Oil is the dominant type of hydrocarbon; the most likely source for the oil in the Findlay arch-Kankakee arch part of the play is the Upper Ordovician Utica Shale and equivalents (fig. 19). The average TOC of this black shale sequence in central and eastern Ohio is about 1.3 weight percent with a maximum of 4 weight percent. On the basis of low maturation indices of the Utica Shale equivalents on the Findlay arch, oil in the Lima-Indiana field probably was derived from the Utica Shale and equivalents in the Appalachian basin and migrated about 150 miles to the field. Oil in the Kankakee arch part of the Lima-Indiana field probably was derived from the Utica Shale in the Michigan basin. The organic-rich Chattanooga Shale was probably the source of oil in Trenton-equivalent reservoirs in the Cumberland saddle-Lexington dome-Nashville dome part of the play. Downsection and long-distance migration is probably required for Chattanooga-derived oil to accumulate in the Ordovician carbonate reservoirs. Time-temperature plots suggest that oil was generated from Utica and Chattanooga Shales in late Paleozoic time, after the majority of the traps had formed.

Stratigraphic traps account for most of the known and anticipated oil fields in the play, but structural traps are locally important. More than 100,000 holes have been drilled on the Findlay and Kankakee arches since the discovery of the Lima-Indiana field in 1885. Numerous exploratory holes have also been drilled in the Cumberland saddle since oil was discovered there in the Lexington Limestone in the 1820's and 1860's. To 1987, this drilling resulted in the development of the Lima-Indiana field, the discovery of a few small satellite fields, and the discovery of at least 120 small oil and gas fields in the Cumberland saddle and adjoining Lexington and Nashville domes. Average depth to reservoirs in the entire province is 1,800 ft or less. The future potential for undiscovered oil in Middle and(or) Upper Ordovician carbonate reservoirs is estimated to be good in the Cumberland saddle part of the play.

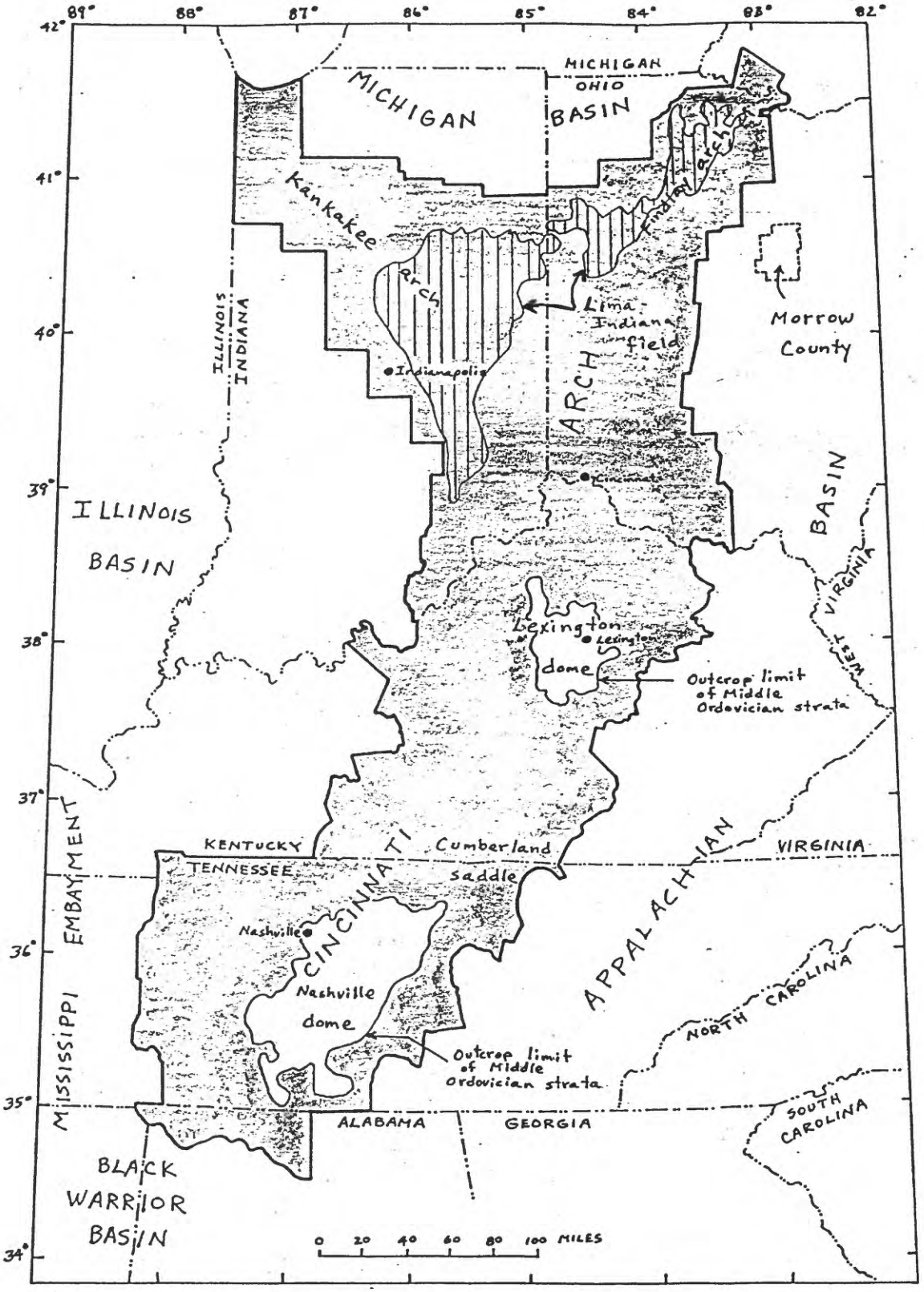

Figure 21. Map of Trenton play.

OIL AND GAS PLAY DATA

PLAY **TRENTON**
PROVINCE **CINCINNATI ARCH** CODE **08-129-030**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0.9**
Gas	**0.1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.1**	**1.4**	**2**	**3.4**	**9.2**	**26**
Gas (x 10^9 CFG)	**6**	**6.1**	**6.2**	**6.6**	**7.5**	**10**	**21**
Reservoir depth (x10^3 ft)							
Oil	**0.5**			**2**			**4**
Gas (non-associated)	**0.5**			**2**			**4**
Number of accumulations	**5**	**6**	**8**	**10**	**14**	**22**	**30**

Average ratio of associated-dissolved gas to oil (GOR)	**500**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

BLACK WARRIOR BASIN (130)

By Robert T. Ryder

INTRODUCTION

The Black Warrior Basin province of Alabama and Mississippi is a foreland basin located in the major structural reentrant between the Appalachian fold and thrust belt to the southeast and the Ouachita fold and thrust belt to the southwest. The northern margin of the basin is bounded by the Nashville dome. Most of the basin and its thrust faulted margins are concealed beneath Tertiary and Cretaceous rocks of the Gulf coastal plain and the Mississippi embayment. The basin is shaped approximately like a kite with its tail facing south. The maximum north-south dimension of the basin is about 190 mi, whereas the maximum east-west dimension is about 220 mi. The overall sedimentary section in the province includes rocks of Paleozoic, Mesozoic, and Cenozoic age (fig. 22) that range in thickness from approximately 7,000 ft along the northern margin to about 31,000 ft in a depocenter in eastern Mississippi. The first gas production in the province was established in 1909 from Pennsylvanian sandstones in Alabama at a depth of 1,400 ft. One play was individually assessed in the province; the Chesterian play (020); other, less significant plays were assessed in the aggregate.

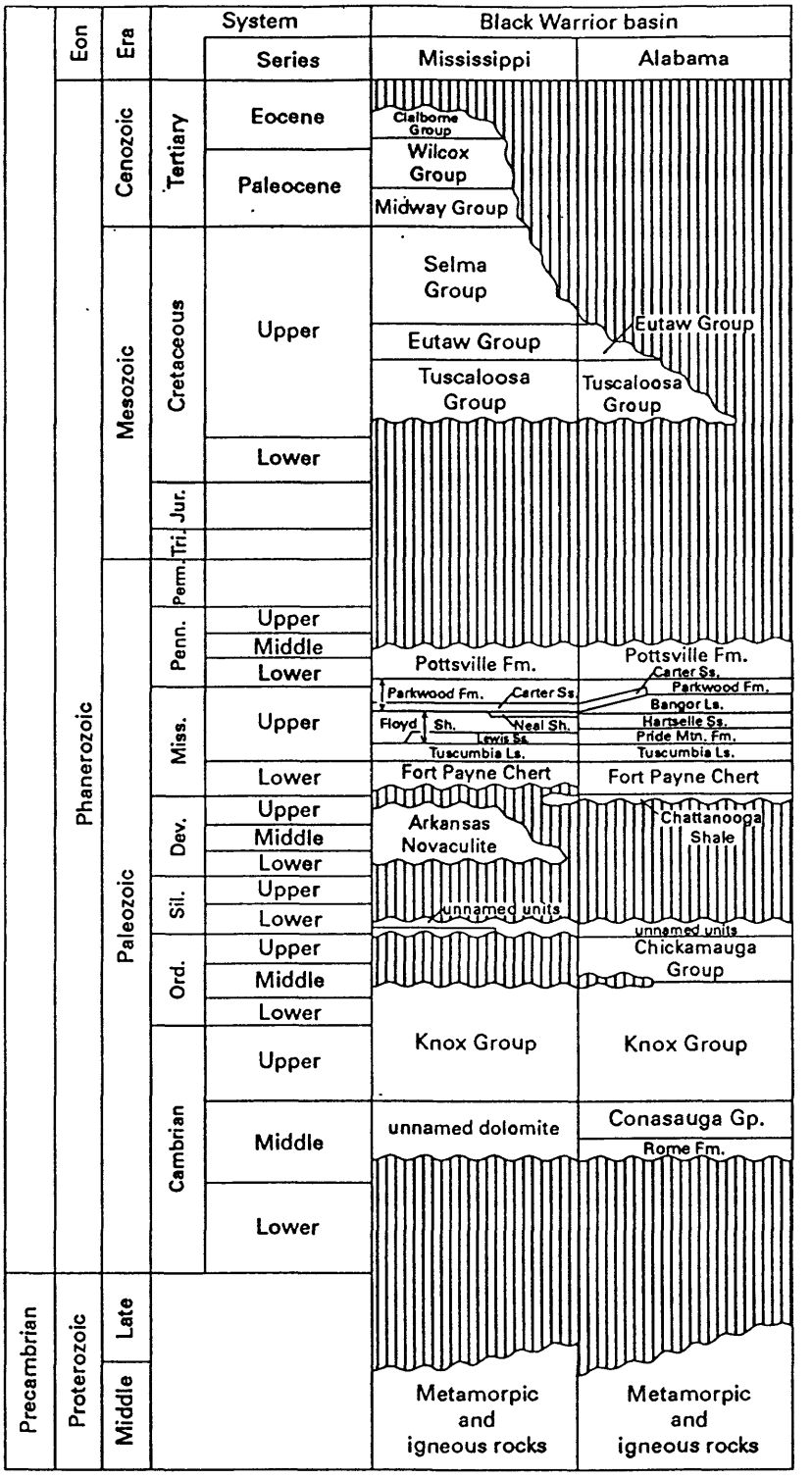

Figure 22. Generalized stratigraphic columns, Black Warrior Basin province

CHESTERIAN PLAY (020)

This play is defined by oil and gas accumulations in deltaic sandstone reservoirs of Upper Mississippian (Chesterian) age, chiefly in anticlinal and normal-fault traps, but many of the traps are influenced by stratigraphy. The play area is triangular shaped with the base facing north and the apex facing south (fig. 23). The base of the triangle is about 210 mi in length and follows the northern outcrop and subcrop limits of Pennsylvanian strata in the basin. The legs of the triangle, defined by the frontal imbricate thrust faults of the Appalachian and Ouachita fold and thrust belts, are about 180 miles in length.

Known reservoir units include the Carter and Hartselle Sandstones, and at least five others. The stratigraphic position of these sandstones is identified in figure 22. In general, the thickness of the reservoirs range from 30 to 50 ft, but locally individual sandstone units may be as thick as 150 ft. Total reservoir thickness ranges from about 100 to 300 ft. Average porosity values of the Carter Sandstone, the major producing reservoir in the play, range from 10 to 17.8 percent, whereas average permeability values of the Carter Sandstone range from 10 to 67 millidarcies.

Dry gas is the predominant type of hydrocarbon in the play, but locally, small amounts of oil, wet gas, and condensate have been produced. Dark gray to black, shallow marine shale in the Upper Mississippian Parkwood Formation, Floyd Shale, and Neal Shale, and possibly the Upper Devonian Chattanooga Shale, is the source of the gas and oil (fig. 22). All of these shale units are excellent oil-and(or) gas-prone source rocks. The low volatile-A bituminous rank of outcropping Pennsylvanian coal beds, Thermal Alteration Index (TAI) values between 2 and 3 in Upper Mississippian shale beds, and Conodont Alteration Index (CAI) values between 1.5 and 2 in outcropping Pennsylvanian strata, indicate that the Upper Mississippian and Upper Devonian source rocks in the basin are mature with respect to oil and gas generation. Maximum hydrocarbon generation and migration from the source rocks probably occurred during Pennsylvanian time when they were buried beneath a southwestward thickening wedge of terrigenous clastic sediments derived from the Appalachian fold and thrust belt. The marked influence of northwest-trending normal faults on Pennsylvanian sedimentation suggests that structural traps were available to Chesterian reservoirs when peak oil and gas migration occurred.

An extensive network of northwest-trending normal faults and derivative anticlinal and horst-block structures are the known and anticipated traps for most of the gas and oil in the play. Stratigraphic controls resulting from sandstone pinchouts and(or) diagenesis in combination with anticlinal structures also contributed to entrapment. Numerous exploratory holes have been drilled in the northern part of the play where the depth to the Chesterian sandstones ranges from 1,000 to 6,000 ft. In contrast, drilling has been sparse in the northwest part of the basin where the depth to the reservoir sandstones is relatively shallow and in the southern part of the basin where the depth to the reservoir sandstones ranges from about 7,000 ft in imbricate-thrust slices to about 18,000 ft in the adjoining block-faulted foreland.

Gas was discovered in the Chesterian sandstone sequence in the basin in 1926, but drilling activity did not increase significantly until the 1970's and 1980's. To 1987, 118 gas fields (78 in Alabama, 40 in Mississippi) and 18 oil fields (13 in Alabama, 5 in Mississippi) have been discovered in the play. The potential for undiscovered gas in the play is estimated to be good.

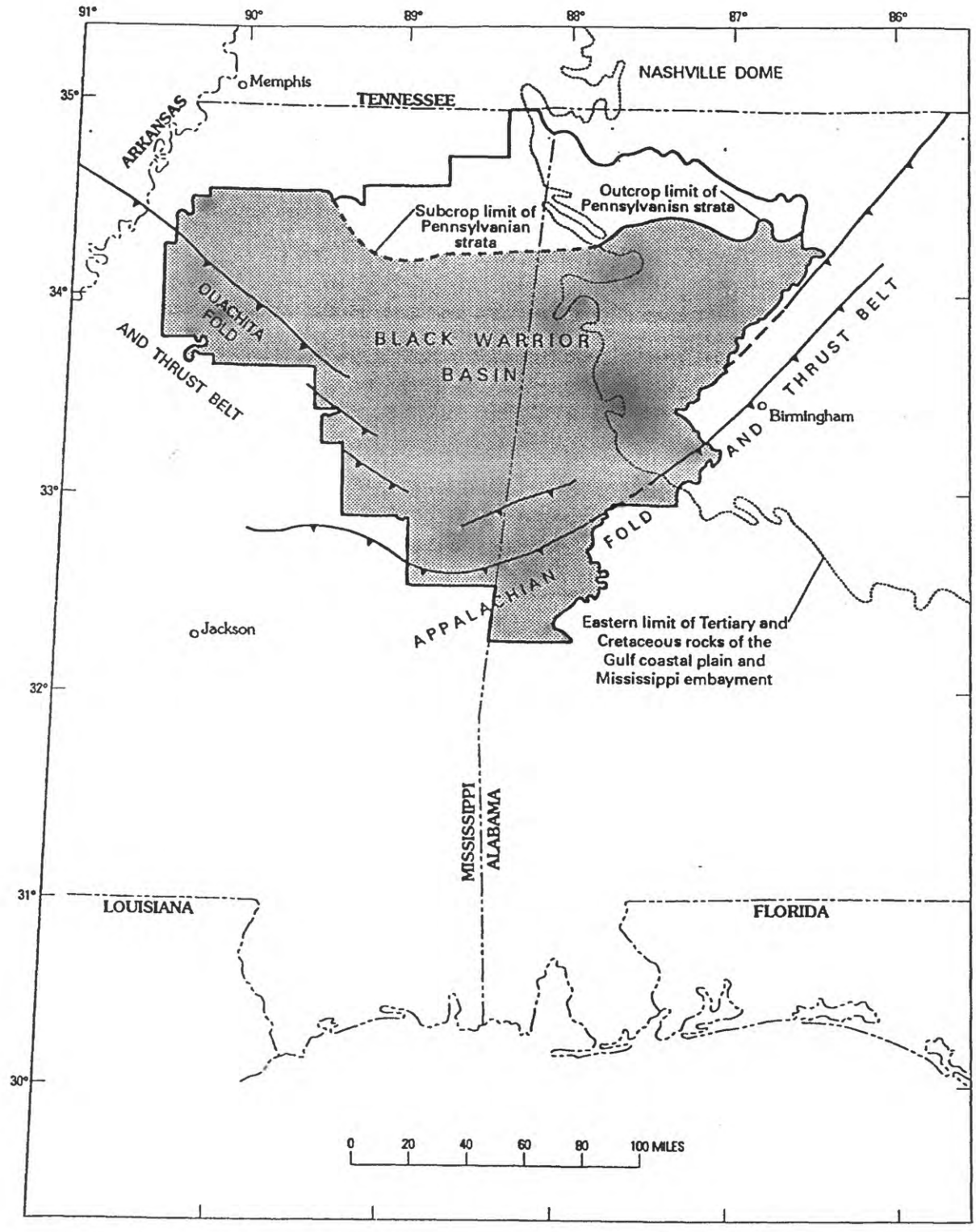

Figure 23. Map of Chesterian play.

OIL AND GAS PLAY DATA

PLAY **CHESTERIAN**
PROVINCE **BLACK WARRIOR BASIN** CODE **08-130-020**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	
Other	
Hydrocarbon type	
Oil	**0.05**
Gas	**0.95**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.04**	**1.2**	**1.5**	**2**	**3.2**	**4.7**
Gas (x 10^9 CFG)	**6**	**7**	**12**	**20**	**37**	**78**	**150**
Reservoir depth (x10^3 ft)							
Oil	**1.5**			**6**			**10**
Gas (non-associated)	**1.5**			**6**			**12**
Number of accumulations	**11**	**14**	**18**	**22**	**27**	**35**	**44**

Average ratio of associated-dissolved gas to oil (GOR)	**6000**	CFG/BBL
Average ratio of NGL to non-associated gas	**1**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

APPALACHIAN BASIN PROVINCE (131)

By Wallace deWitt, Jr.

INTRODUCTION

The Appalachian Basin province is a broad, elongate synclinorium 75-350 mi wide and more than 1,000 mi long extending from Lake Ontario in New York generally south-westward to Alabama. The western margin of the province is the east flank of the Cincinnati arch; the basin extends eastward from this point to and under the Blue Ridge Thrust Belt (132) and Piedmont (133) provinces. Resources in these two provinces were assessed separately, however. Rocks on the west flank of the basin, in the Appalachian Plateaus segment, dip gently eastward; in contrast, rocks on the east flank of the basin, in the Valley and Ridge segment, comprise a belt of greatly deformed Paleozoic strata that were thrust westward and are characterized by elongate folds and thrust sheets resulting from the Allegheny orogeny at the close of the Paleozoic. The basin contains up to 50,000 ft of sedimentary rocks ranging in age from Cambrian to Permian; however, individual plays identified in this assessment involve rocks no younger than Upper Devonian (fig. 24).

Blind thrusts under the Appalachian Plateaus segment of the basin form long anticlinal folds involving extensive fracture porosity reservoirs that have been important in trapping hydrocarbons, and have been key drilling targets for many years. Oil and gas have been produced in the Appalachian Basin province since the first discovery of producible oil from a drilled well in the United States at the Drake wildcat in northwestern Pennsylvania in 1859. Most of the early oil and gas discoveries were found in Upper Devonian and younger sandstone reservoirs. Major gas accumulations were found later in the Lower Devonian Oriskany Sandstone in the 1930's, and additional oil was discovered in 1965 in older sandstone reservoirs of Lower Silurian age. Since 1860, the Appalachian Basin province has produced more than 3 BBO and more than 35 TCFG cumulatively.

Seven principal plays were defined and individually assessed; they are discussed in the following order: Rome Trough (020), Knox Gas (040), Knox Oil (050), Lower Silurian Clastic (060), Upper Devonian Clastic (070), Trenton (080), and Oriskany (090). Plays of local extent, which are confined mainly to the younger Paleozoic rocks and have been largely exhausted, were assessed in the aggregate.

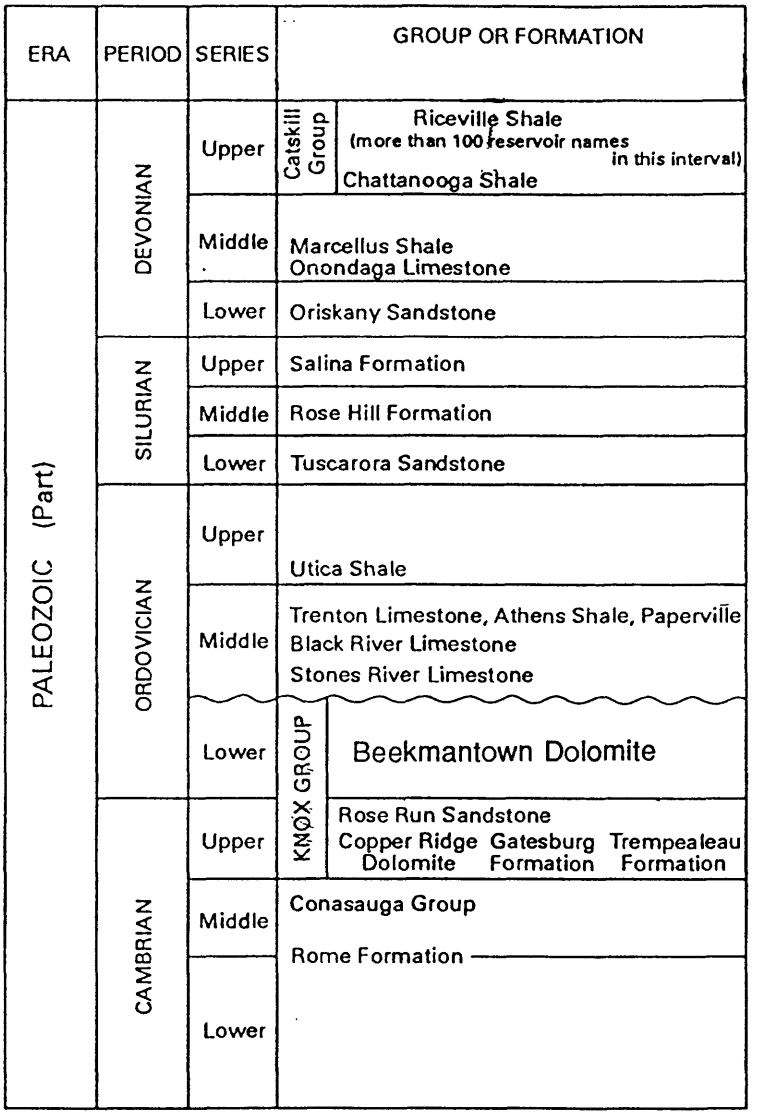

Figure 24. Generalized stratigraphic column, Appalachian Basin province.

ROME TROUGH PLAY(020)

The play is a combination structural-stratigraphic trap play located in a 40,000 mi^2 complexly fault-bounded aulacogen under parts of Kentucky and West Virginia (fig. 25). The Rome trough is a graben, filled with as much as 8,000 ft of Middle and Upper Cambrian rocks that contain oil and associated gas in Kentucky and dry, non-associated gas in West Virginia.

Reservoirs are commonly calcareous sandstone or siltstone of Middle and Upper Cambrian age, ranging in thickness from a few to more than 60 ft. Porosity and permeability range from marginal to good. Locally, a little gas, oil, or salt water has been found almost to the base of the trough sequence.

Source rocks consist mainly of dark gray to brownish-black marine shales in the Cambrian Rome or Conasauga Formations. They are intercalated with black limestone and siltstone in a 2,000 ft thick interval in western West Virginia and appear to be confined to the trough. In the shallower eastern Kentucky segment of the trough, rocks are in the oil generation zone, whereas eastward and deeper in the trough they pass into the dry, nonassociated gas generation zone. Maturation of source rocks increases eastward into the deeper part of the trough in Pennsylvania where source beds are super-mature and beyond the level for gas generation. The time of greatest hydrocarbon generation was probably late in the Paleozoic when the trough was most deeply buried and source rocks were subjected to maximum maturation temperatures.

Although the Rome trough is a complex network of normal and reverse faults, permeability barrier-controlled stratigraphic traps contain the play's oil and gas. Shaly strata within the trough sequence seal reservoirs, and the trough is completely sealed by the overlying 2,000 to 4,000 ft of Knox Group carbonate rocks.

Drilling depths to reservoirs range from about 6,000 ft in Kentucky to more than 14,000 ft in central West Virginia. The base of the trough plunges from about 5,000 ft subsea in eastern Kentucky to about 20,000 ft subsea in central West Virginia. Seismic data suggest the base of the trough may be as deep as 30,000 ft subsea in southwestern Pennsylvania.

Drilling in the play began in Kentucky in the 1950's and 1960's. A well that produced 32 BOPD was drilled in eastern Kentucky in 1969. Drilling spread eastward along the trough, and in the 1970's, Exxon Co., USA drilled 6 wells in the 14,000 to 20,000 ft range in western and central West Virginia. Several of these found good shows of gas, and one well produced 9 MMCFGPD. However, the well was flooded by salt water after about 6 months. Eastern Kentucky contains several small gas fields in the play, with individual wells producing from 0.5 to 2.0 MMCFGPD.

The play is a frontier play because of the great drilling depths in hard rocks, the small extent and thickness of reservoir rocks, the difficulty of locating stratigraphic traps in a deep, complexly faulted graben, and the general absence of seismic data to delineate the trough's geometry. Conversely, only about 30 wildcat wells have been drilled in the 40,000 mi^2 of the play. Oil and gas have been produced from the Cambrian sequence, source beds are present, and porous and permeable strata occur almost to the trough's base in both Kentucky and West Virignia. The future potential appears to be moderately good for the discovery of small-size gas and oil fields in the western part of the play. Because of increased thermal maturity and depth of burial in Pennsylvania, the play will probably not contain gas in exploitable amounts.

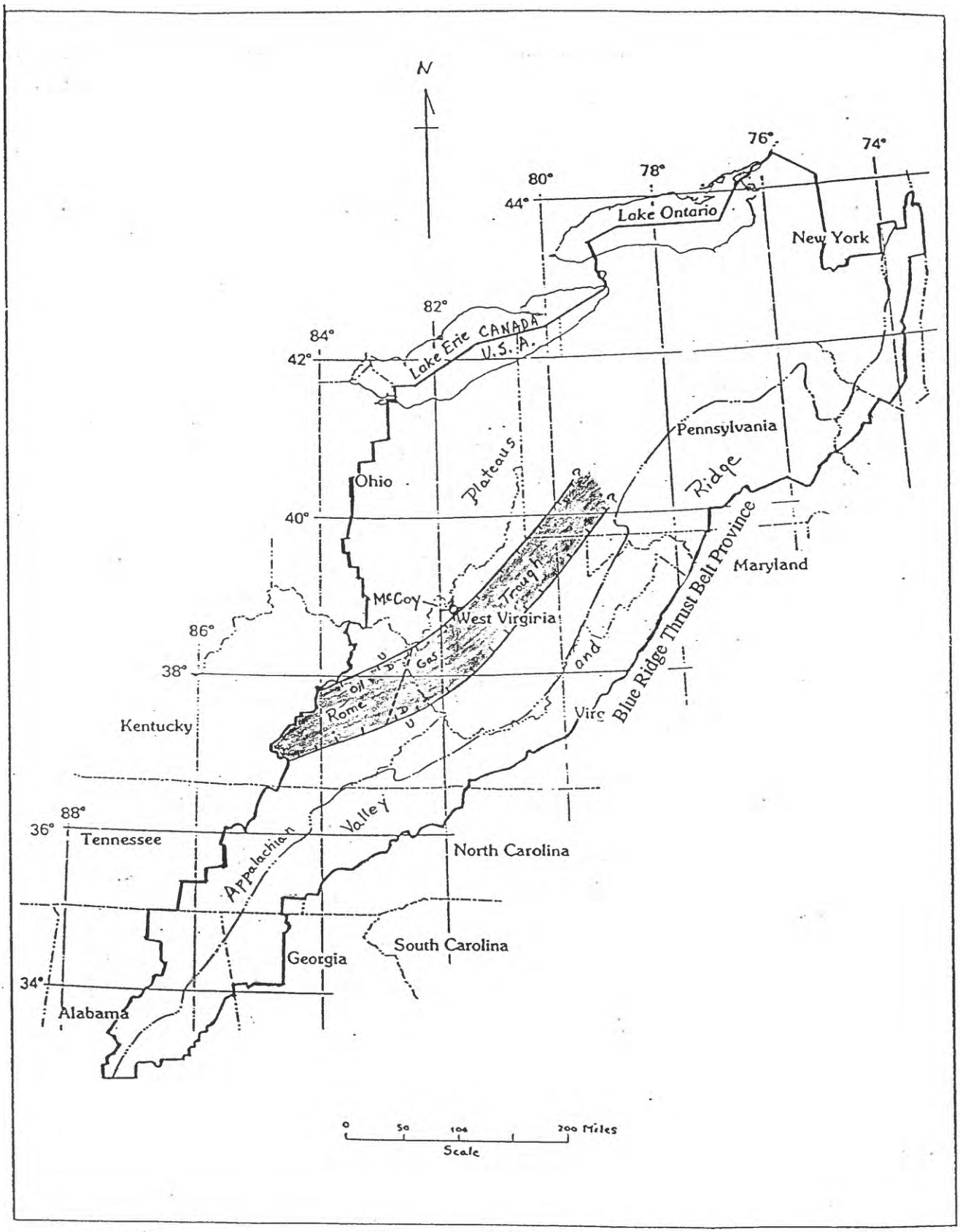

Figure 25. Map of Rome Trough play.

OIL AND GAS PLAY DATA

PLAY **ROME TROUGH**
PROVINCE **APPALACHIAN BASIN** CODE **08-131-020**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assesed	**0.50**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	
Other	
Hydrocarbon type	
Oil	**0**
Gas	**1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gas (x 10^9 CFG)	**40**	**50**	**75**	**110**	**200**	**400**	**600**
Reservoir depth (x10^3 ft)							
Oil	**0**			**0**			**0**
Gas (non-associated)	**7**			**12**			**30**
Number of accumulations	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Average ratio of associated-dissolved gas to oil (GOR)	**0**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

KNOX GAS PLAY (040)

The play consists of a combination of stratigraphic and structural traps in karstic carbonate rocks of the Cambrian-Ordovician Knox Group, siliciclastic residuum associated with an unconformity, and fracture porosity in structural traps. Upper Cambrian and Lower Ordovocian tidal and subtidal carbonate rocks of the Knox underlie about 158,000 mi^2 from New York to Alabama, and extend westward into Ohio, Kentucky, and Tennessee (fig. 26). The play is bounded on the north by Canada, on the east by the Blue Ridge, on the south by a thick cover of Gulf coastal plain rocks, and on the west by the Knox Oil play (050), or the province boundary. Rocks in the play range in thickness from 4,000 ft in Alabama to more than 6,000 ft in Pennsylvania. The Middle Ordovician unconformity thins the sequence westward.

Although most of the rocks in the play are dolomitic, the Upper Cambrian Gatesburg Formation of Pennsylvania and equivalent Copper Ridge Dolomite to the south contain zones of quartz sandstone, which are locally several hundred feet thick. In northwestern Pennsylvania and contiguous Ohio, leached sandstones of the Gatesburg below the Middle Ordovocian unconformity are reservoirs. Near the Bradford field (in the Minard Run field) in north-central Pennsylvania (fig. 26), fracture porosity appears to be important in the Gatesburg reservoir. To the south in Tennessee's Valley and Ridge, fracture-porosity reservoirs yield gas in structural traps in the upper part of the Knox Group.

Source rocks appear to be basinal marine Middle and Upper Ordovocian black shales, such as the Utica and Athens. The quality of the source rocks is good, although at present these rocks are in the dry, non-associated gas zone. Gas has been produced locally in the play from New York to Tennessee.

Traps are combination stratigraphic and structural in the western part of the play, whereas in the Valley and Ridge, structural traps dominate. Shale and carbonate rocks in the lower part of the Trenton Limestone seal reservoirs in the upper part of the Knox Group. Scant data suggest that migration of oil and gas occurred mainly at the close of the Paleozoic Era when the strata were most deeply buried and subjected to maximum geothermal temperatures. Hot saline solutions migrating westward from deep in the basin during the Allegany orogeny may have aided in the migration of hydrocarbons. Drilling depths range from about 4,500 ft in Tennessee to 7,200 ft in northwestern Pennsylvania, and 10,000 ft near the Bradford field in north-central Pennsylvania.

Only dry, non-associated gas has been produced in the play; most wells were drilled along the western edge of the play. In general, the fields are small and contain one or two wells with ultimate recoveries in the 1 to 10 BCFG range. A moderate future potential is estimated for the play, however, much of the broad area of the play remains to be explored. Factors that tend to inhibit future exploration include great drilling depths in very hard rocks, the difficulty of locating fracture porosity zones in complex structural traps, and the presence of considerable salt water with the gas in northwestern Pennsylvania. However, the great expanse of unexplored area in the play may be prospective for undiscovered gas resources.

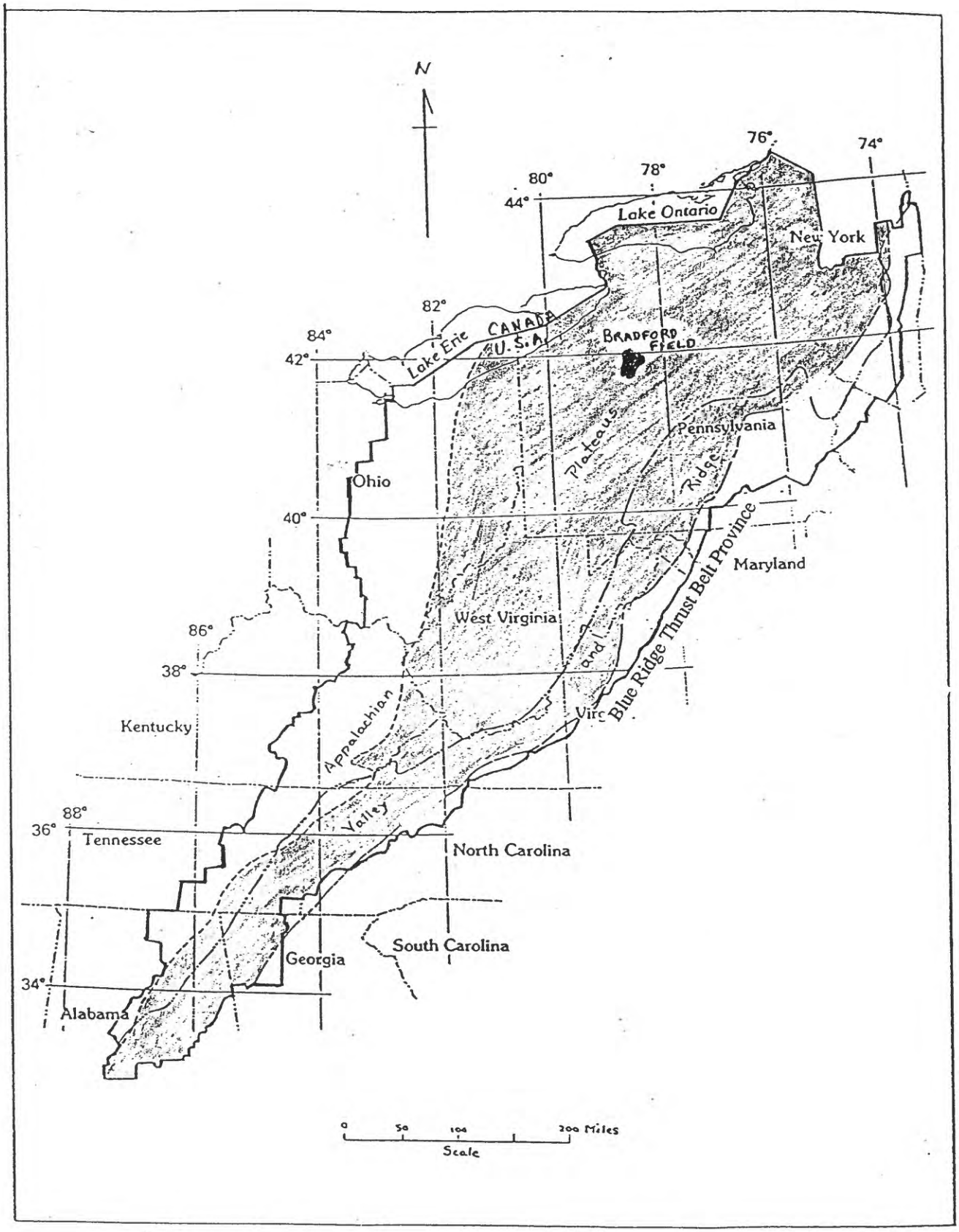

Figure 26. Map of Knox Gas play.

OIL AND GAS PLAY DATA

PLAY **KNOX GAS**
PROVINCE **APPALACHIAN BASIN** CODE **08-131-040**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assesed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0**
Gas	**1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gas (x 10^9 CFG)	**100**	**200**	**350**	**500**	**900**	**1500**	**2500**
Reservoir depth (x10^3 ft)							
Oil	**0**			**0**			**0**
Gas (non-associated)	**4**			**10**			**15**
Number of accumulations	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Average ratio of associated-dissolved gas to oil (GOR)	**0**	CFG/BBL
Average ratio of NGL to non-associated gas	**2**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

KNOX OIL PLAY (050)

The play is characterized by oil accumulations in karstic-reservoir stratigraphic traps in Knox Group strata beneath the Middle Ordovician unconformity. Dolomitic rocks in the play range in thickness from about 100 ft of Upper Cambrian strata beneath the unconformity in northern Ohio, to more than 2,500 ft of Upper Cambrian and Lower Ordovocian rocks in Lee County, Virginia. The play is bordered on the east and south by the Knox Gas play (040), and on the west and north by the province boundary (fig. 27).

Reservoirs in Morrow County in central Ohio are karstic, residual hills with a maximum thickness of 160 ft and are located beneath the Middle Ordovician unconformity. Eastward in Ohio, a zone of carbonate cemented quartz sandstone, the Upper Cambrian Rose Run Sandstone, underlies the unconformity. Rose Run reservoirs, which are 5 to 50 ft thick, contain oil and associated gas. To the south, in southern Kentucky and contiguous Tennessee, Lower Ordovocian Knox rocks contain karstic reservoirs associated with the unconformity. Oil-productive fracture porosity reservoirs in thrust-fault structural traps occur in the Valley and Ridge area of Lee County, Virginia.

The main source rocks are Middle and Upper Ordovician marine black shales, the Utica and Athens. In the Cumberland saddle and southward in Tennessee, Upper Devonian Chattanooga marine black shale overlies the Knox and may be a secondary source rock. Source rock quality is good, and maturation levels are in the oil generation zone in the eastern segment of the play. Migration occurred at the close of the Paleozoic Era when source rocks were most deeply buried and attained maxium geothermal temperature.

Traps are dominantly stratigraphic except in the Valley and Ridge where structural traps predominate. Traps are generally small because of variation in permeability of reservoir rocks. Seals are shale and carbonate rocks of the Trenton Limestone except in the Valley and Ridge where faulted carbonate rocks seal fracture-porosity reservoirs. Drilling depths range from about 1,800 ft in southern Kentucky, to about 2,900 ft in Morrow County, Ohio, and more than 7,000 ft to the Rose Run Sandstone of southeastern Ohio.

Exploration in the play began in southern Kentucky in 1900 as the result of deepening of wells from the Trenton Limestone. Although drilling continues there today, scant production data are available for wells and fields in the area. Intensive exploration in the play really began in 1961 with the discovery of karstic reservoirs in the Cambrian Trempealeau Formation in Morrow County, Ohio. More than 40 MMBO has been produced to date from fields in much of Morrow County. Exploration eastward from Morrow County resulted in discoveries of oil and gas in the Rose Run Sandstone in eastern Ohio. Currently, the Rose Run Sandstone is being actively developed, but little production data are presently available. Several recently drilled wells have found small quantitites of oil in the vicinity of Rose Hill in Lee County, Virginia. These wells are the first to produce oil from the Knox Group in the Valley and Ridge area of the play.

Much of the play remains to be explored, and the future potential for the discovery of small to moderate sized oil fields, in the 0.5 MMBO to 5.0 MMBO range is good. Factors which may inhibit future exploration in the play include; 1) the difficulty of locating specific targets in either buried karstic hills or in structurally complex areas in the Valley and Ridge area, 2) the problem of delineating the edge of permeable zones in the Rose Hill Sandstone, and 3) the need for more geophysical data to help locate specific drilling targets.

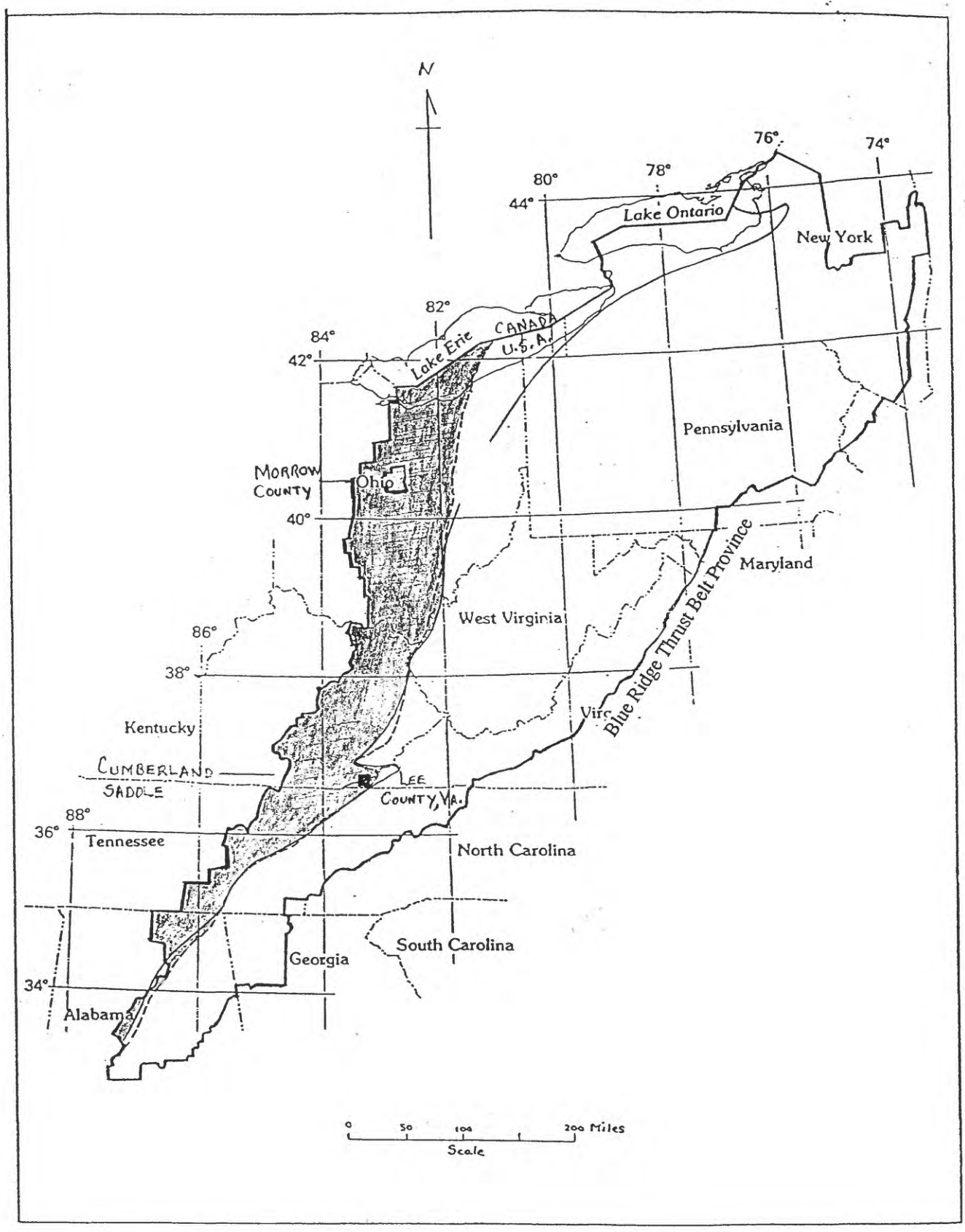

Figure 27. Map of Knox Oil play.

OIL AND GAS PLAY DATA

PLAY **KNOX OIL**
PROVINCE **APPALACHIAN BASIN** CODE **08-131-050**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assesed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**6**	**10**	**15**	**20**	**27**	**37**	**50**
Gas (x 10^9 CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth (x10^3 ft)							
Oil	**1.5**			**3**			**7.5**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Average ratio of associated-dissolved gas to oil (GOR)	**500**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

LOWER SILURIAN CLASTIC PLAY(060)

The play is defined by oil and gas accumulations in western stratigraphic and eastern structural traps in Lower Silurian Tuscarora Sandstone (and equivalent units) clastic reservoirs. It underlies about 117,500 mi^2 of the northern half of the Applachian Plateaus and the Valley and Ridge (fig. 28). The play is bounded on the north, east, and southeast by outcrop and on the west by the feather edge of reservoir sandstone and siltstones. In the west, it is primarily a stratigraphic play, and in the east it is predominantly a structural play.

Reservoirs are contained in a westward thinning deltaic sequence, grading from terrestrial coarse-grained pebbly sandstone to marine fine-grained siltstone of the Tuscarora Sandstone and its equivalents (Medina Group, Clinton, Big Six, Clinch, et cetera). Reservoirs are commonly lenticular and range in thickness from a feather edge to more than 75 ft . Reservoir quality ranges from good in oil-bearing sandstones, to marginal in tight, low-permeability gas-bearing siltstones.

Source rocks appear to be marine Middle and Upper Ordovician black shales, such as the Utica and Athens. Thermal maturity ranges from the oil generation zone in central Ohio eastward to the dry, non-associated gas zone in western Pennsylvania and adjacent New York, and to supermature east of the Conodont Alteration Index (CAI) 4.5 isograd in the Valley and Ridge (fig. 28). Maximum oil generation and migration appears to have occurred during the Permian and Triassic Allegany orogeny, when source rocks were most deeply buried and subjected to maximum geothermal temperature. Hot, saline fluids migrating through the source rocks may have enhanced maturation.

Stratigraphic traps are abundant in the western part of the play. From central New York to central West Virginia, structural traps become more important and are dominant in the Valley and Ridge area. In size, stratigraphic traps range from a few acres around a single well to more than 640 acres. Intercalated shales or shales in the Silurian Rose Hill Formation overlying the Tuscarora (fig. 22) seal reservoirs. Drilling depths range from about 1,800 ft in central Ohio to more than 12,500 ft in central Pennsylvania.

Exploration began in the play before 1890 in Ohio, and since that time, more than 150,000 wells have been drilled in a seven-state area of the play. Oil and associated gas are produced mainly in Ohio, whereas to the east dry, non-associated gas is found in New York, Pennsylvania, and West Virginia. Oil fields range in size from single wells producing a few million barrels to the large East Canton field in eastern Ohio, which has produced more than 70 MBBO to date (fig. 28). Production data for gas fields is regionally incomplete; however, typical gas fields in Ohio have cumulative production of as much as 40 BCFG, in Pennsylvania 68 BCFG, and in West Virginia 24 BCFG. Much of the play's western oil-productive segment has been thoroughly explored; drilling is concentrated largely in the eastern, gas-bearing segment of the play.

Factors that may inhibit exploration in the dry, non-associated gas segment of the play include deeper drilling depths, a greater inert gas component with increasing depth, and an eastward transition to dry, terrestrial quartzitic sandstone in the Valley and Ridge area. However, the future potential is estimated to be moderate to good that small to medium-sized gas fields will be found in the dry gas segment of the play from New York to south-central West Virginia.

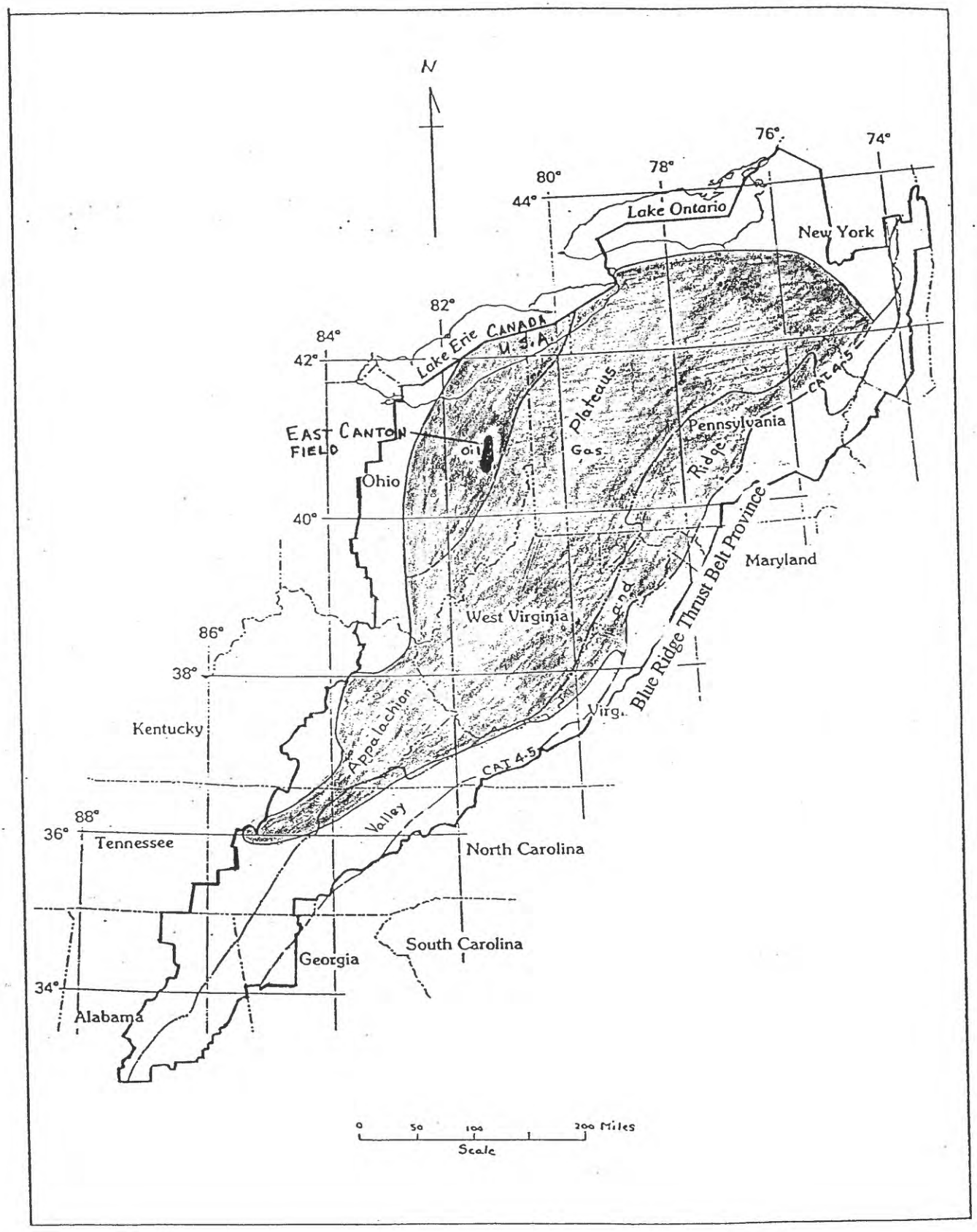

Figure 28. Map of Lower Silurian Clastic play.

OIL AND GAS PLAY DATA

PLAY **LOWER SILURIAN CLASTIC**
PROVINCE **APPALACHIAN BASIN** CODE **08-131-060**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assesed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	
Other	
Hydrocarbon type	
Oil	**0**
Gas	**1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gas (x 10^9 CFG)	**800**	**1000**	**1300**	**1600**	**2100**	**3000**	**4000**
Reservoir depth (x10^3 ft)							
Oil	**0**			**0**			**0**
Gas (non-associated)	**2.5**			**6**			**12**
Number of accumulations	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Average ratio of associated-dissolved gas to oil (GOR)	**0**	CFG/BBL
Average ratio of NGL to non-associated gas	**5**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

UPPER DEVONIAN CLASTIC PLAY (070)

The play is characterized by oil and gas accumulations in combination stratigraphic and structural traps in numerous (approximately 100) lenticular sandstone and siltstone reservoirs in the Catskill Group; it underlies an area of about 40,000 mi^2 in the northern part of the basin (fig. 29). It is bounded on the north, east, and south by outcrop and on the west by impermeable shale. Upper Devonian rocks range in thickness from about 300 ft in Ohio to more than 5,000 ft in south-central Pennsylvania, although reservoir rocks commonly comprise only 2 to 15 percent of the total thickness.

Reservoirs range from tight, distal turbidite sandstone to permeable shoreline pebbly sandstones (Venango sands), and range in thickness from 20 to more than 700 ft . The greater thickness is distributed through as many as 13 stacked reservoirs. Permeability and porosity are marginal in siltstones and very good in coarse-grained pebbly sandstone. More than 100 local and regional reservoir names (Gantz, Venango, Warren, Bradford, Balltown, et cetera) have been used historically in the play.

Source rocks are Middle and Upper Devonian marine black shales rich in organic matter, such as the Marcellus Shale, which underlie and are intercalated with reservoirs in the play. These shales are about 250 ft thick in outcrop in Ohio and more than 1,000 ft thick in central New York and eastern West Virginia. The shales are presently in the oil generation zone in eastern Ohio and pass eastward into the deeper, dry non-associated gas zone in central Pennsylvania. Data, although minimal, indicate that the greatest migration of hydrocarbons occurred during the Permian and Triassic, which were times of the greatest depth of burial and maximum geothermal temperature of source rocks.

Stratigraphic traps are most important in the western part of the play, particularly in western Pennsylvania. Eastward, under the eastern part of the Appalachian Plateaus, structural traps with fracture porosity become paramount. Oil and associated gas are present in the western part of the play, whereas only dry, non-associated gas is present in the more deeply buried eastern portion. Intercalated shales adequately seal reservoirs.

Drilling depths range from 70 ft in northwestern Pennsylvania to more than 6,500 ft in northeastern West Virginia. In 1859, America's first commercial oil well, Drake's original well, was drilled into a stray sandstone in the Upper Devonian Riceville Shale in the play, in northwestern Pennsylvania. Since then, more than 1,000 oil and gas fields have been found. These range from one well fields that produced a few thousand barrels of oil, to the giant Bradford field (fig. 29), which was discovered in 1875 in north-central Pennsylvania, and has produced more than 676 MMBO to date.

Although large in area, the play has been explored continuously for the past 131 years. Much of its western part has been thoroughly explored, however, drilling continues in the vicinity of larger oil fields. By about 1900 the eastern limit for oil generation and accumulation, which lies slightly east of the CAI 2.5 isograd, had been clearly delineated. From the CAI 2.5 isograd to the east edge of the play, only dry, non-associated gas has been found. At present, most exploratory drilling and development is in this segment of the play. Loss of permeability limits production of oil and gas at the western edge of the play. In the Valley and Ridge area, rocks equivalent to the productive strata are terrestrial red beds of the Catskill Group with little potential for oil or gas. The future potential for undiscovered oil fields is minor, whereas the potential is moderate to good for small to medium sized, non-associated gas fields in the eastern segment of the play.

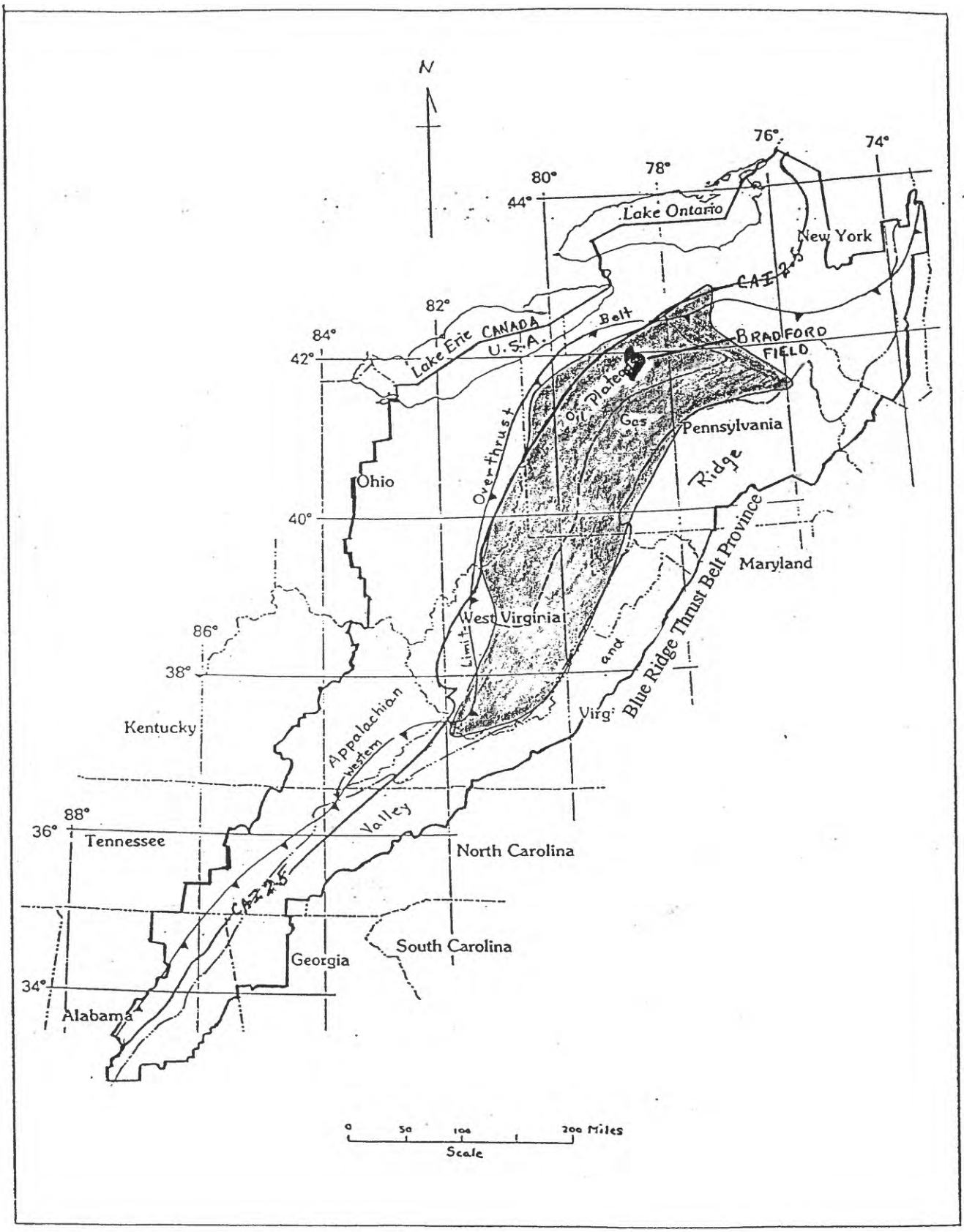

Figure 29. Map of Upper Devonian Clastic play.

OIL AND GAS PLAY DATA

PLAY **UPPER DEVONIAN CLASTIC**
PROVINCE **APPALACHIAN BASIN** CODE **08-131-070**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assesed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	
Other	
Hydrocarbon type	
Oil	**0**
Gas	**1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gas (x 10^9 CFG)	**250**	**350**	**550**	**700**	**900**	**1300**	**1600**
Reservoir depth (x10^3 ft)							
Oil	**0**			**0**			**0**
Gas (non-associated)	**2.5**			**3.5**			**4.5**
Number of accumulations	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Average ratio of associated-dissolved gas to oil (GOR)	**0**	CFG/BBL
Average ratio of NGL to non-associated gas	**1**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

TRENTON PLAY (080)

The play is defined by oil and gas accumulations in karstic reservoirs in the Middle Ordovician Stones River, Black River, and Trenton Limestones, in stratigraphic traps in the western part of the play and dominantly structural traps in the eastern part (Valley and Ridge). It underlies about 175,000 mi^2 of the province, from New York to Alabama, and is bounded on the east by outcrop and on the west by the province boundary (fig. 30).

Reservoirs in the Stones River, Black River, and Trenton are biohermal limestones, karstic limestone associated with unconformities, and localized zones of dolomite in the western part of the play, and fractured limestone in the Valley and Ridge area. Black shales in the Trenton act as both reservoir and source beds with limestone seals and are productive of gas in northeastern New York.

Source beds are basinal black marine shales in the Utica and Athens that range in thickness from 300 to 2,000 ft ; they occur east of the shelf carbonate rocks, intertongue with carbonate strata, and overlie much of the northern third of the play. Source rocks are in the oil generation zone in central Ohio and grade eastward into the dry, non-associated gas generation zone in the northern part of the Valley and Ridge area. In the Cumberland saddle of south-central Kentucky, unconformities bring Upper Devonian black shale source beds to a position directly above the Trenton in the play. These black shales may be a secondary source for hydrocarbons in that part of the play. In Lee County, Virginia, some Trenton oil may have migrated from Trenton carbonate rocks during Late Paleozoic thrusting. Maximum oil generation and migration probably occurred during or shortly after the Allegany orogeny closed the Paleozoic Era, when source rocks were most deeply buried and subjected to maximum geothermal temperatures.

Stratigraphic traps modified by small scale structures are common in the play's western segment. Dry gas occurs in deep, subtle traps in central New York, whereas oil and gas occur in shallower structural traps in the Valley and Ridge area of southwestern Virginia and adjacent Tennessee. Carbonate or shale beds commonly are seals for reservoirs. Locally, permeability barriers limit the horizontal extent of reservoirs. Drilling depths range from less than 1,000 ft in south central Kentucky to more than 7,500 ft in central New York. Oil and gas are found at depths between 1,000 and 3,500 feet in Lee County, Virginia.

Drilling began in the Cumberland saddle area shortly after the Civil war and continues there today. Scant production data are available for wells or fields in this area. Drilling in the Valley and Ridge in Virginia began in 1942 with the discovery of oil in anticlinal traps. Two fields to date have produced slightly more than 300,000 barrels of high gravity oil from this type of trap.

Much of the play is relatively deeply buried and remains to be explored; eventually, drilling may extend into this deeper part of the play. The possibilities are moderate to good that small to large gas fields may be found in the play from central New York to southern Tennessee. Factors that may inhibit exploration are increased drilling depths to the east, an absence of good seismic reflectors in the play for structural analysis, the difficulty of locating subtle structural traps, and the relatively small size of many of the fields found to date.

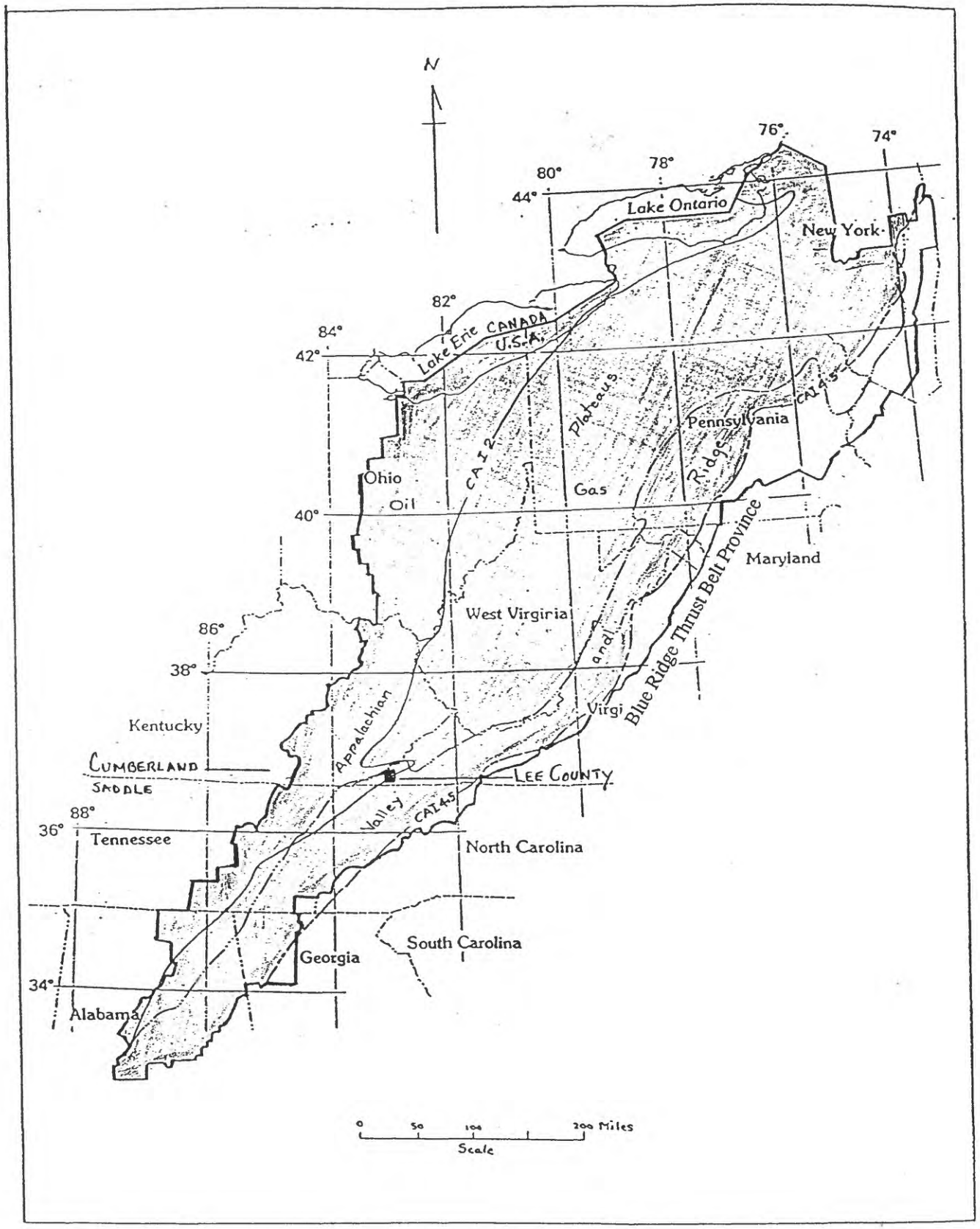

Figure 30. Map of Trenton play.

OIL AND GAS PLAY DATA

PLAY **TRENTON**
PROVINCE **APPALACHIAN BASIN** CODE **08-131-080**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assesed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0**
Gas	**1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gas (x 10^9 CFG)	**75**	**200**	**450**	**650**	**1000**	**1500**	**2000**
Reservoir depth (x10^3 ft)							
Oil	**0**			**0**			**0**
Gas (non-associated)	**0.5**			**7**			**13**
Number of accumulations	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Average ratio of associated-dissolved gas to oil (GOR)	**0**	CFG/BBL
Average ratio of NGL to non-associated gas	**1**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

ORISKANY PLAY (090)

The play is characterized by mainly gas accumulations in stratigraphic and structural traps in the Lower Devonian Oriskany Sandstone underlying about 88,000 mi^2 in the northern two-thirds of the Appalachian basin (fig. 31). It is bounded on the north, west, and southwest by areas of nondeposition of sandstone and on the east by outcrop. The Oriskany Sandstone is a blanket sandstone that ranges in thickness from a feather edge in eastern Ohio to more than 300 ft in Maryland.

Reservoirs range from porous and permeable sandstone in the west to tightly cemented, intensely fractured sandstone in the overthrust belt area of the Appalachian Plateaus. Reservoir thickness ranges from about 5 ft to the full 300 ft thickness of the Oriskany Sandstone. Porosity and permeability ranges from poor in silty sandstone facies to excellent in western stratigraphic traps and in fractured sandstone in eastern structural traps.

Middle and Upper Devonian marine black shales, particularly the Marcellus Shale, are the source rocks; these black shales are 300 ft thick in eastern Ohio and more than 1,000 ft thick in eastern West Virginia. Source rocks are in the oil generation zone in Ohio and grade eastward into the dry, non-associated gas zone under the eastern two-thirds of the Applachian Plateaus. Maximum generation and migration of hydrocarbons took place during the Permian and Triassic, when source rocks were most deeply buried and subject to maximum geothermal temperatures.

Stratigraphic traps are dominant in the western 24,000 mi^2 of the play. Eastward into the overthrust belt area, anticlinal traps become dominant with zones of fracture porosity in sandstones serving as major reservoirs in the eastern two-thirds of the Appalachian Plateaus and adjacent Valley and Ridge. Oil has been found sparingly in the Oriskany, mainly in Ohio, whereas dry, non-associated gas is abundant in the overall play. The Onondaga Limestone seals Oriskany reservoirs in the western part of the play, whereas thick Devonian shales seal Oriskany traps in the area of overthrusting. Drilling depths range from about 1,600 ft in northeastern Ohio to about 8,500-9,300 ft to structural traps in central Pennsylvania and adjacent eastern West Virginia.

A few wildcat wells initially produced some gas and oil from the Oriskany in northern Ohio in about 1900. However, intensive exploration of the play began about 1930, and more than 225 fields have been found to date. These range in size from single well fields with an ultimate yield of 0.5 BCFG, to the anticlinal Punxsutawney-Driftwood field complex in central Pennsylvania with cumulative production in excess of 385 BCFG, to the giant Elk-Poca stratigraphic accumulation in western West Virginia with a cumulative production of more than 1 TCFG.

Because of the intense exploration since the 1930's, much of the stratigraphic trap segment of the play has been thoroughly tested, as have the larger structural traps of the overthrust belt area. At present, most exploration is focused on smaller, subtle traps in areas where the Oriskany is involved in faulting under the eastern Appalachian Plateaus and adjacent Valley and Ridge. Smaller structures can be located by seismic methods; however, zones of fracture porosity in the Oriskany are difficult to locate and delineate. Increasing structural complexity of reservoirs and greater drilling depths are factors that will tend to inhibit future exploration in the play. The future undiscovered resource potential for gas in the play is estimated to be fair to good. Small to medium sized fields, ranging in size from 5 to 40 BCFG, may be found in the overthrust belt area of the play. However, the probability of finding additional oil resources in the play is remote.

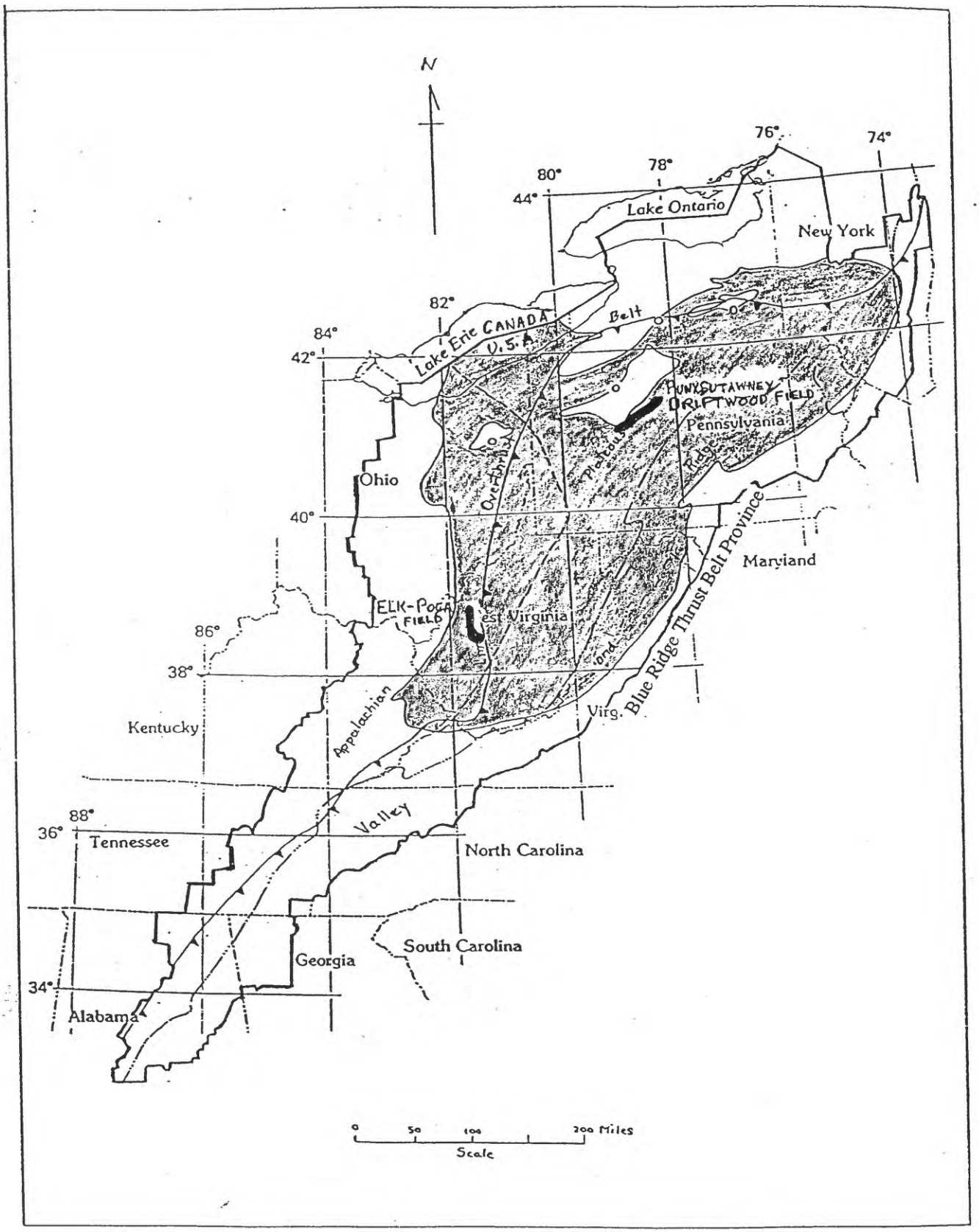

Figure 31. Map of Oriskany play.

OIL AND GAS PLAY DATA

PLAY **ORISKANY**
PROVINCE **APPALACHIAN BASIN** CODE **08-131-090**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assesed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	
Other	**X**
Hydrocarbon type	
Oil	**0**
Gas	**1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gas (x 10^9 CFG)	**300**	**450**	**750**	**1000**	**1500**	**2300**	**3000**
Reservoir depth (x10^3 ft)							
Oil	**0**			**0**			**0**
Gas (non-associated)	**6**			**7.5**			**9**
Number of accumulations	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Average ratio of associated-dissolved gas to oil (GOR)	**0**	CFG/BBL
Average ratio of NGL to non-associated gas	**1**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

BLUE RIDGE THRUST BELT PROVINCE (132)

By Wallace deWitt, Jr.

INTRODUCTION

The province underlies parts of eight States from central Alabama to southern Pennsylvania. It is the surface expression of the eastern boundary of overthrusting that characterizes the Appalachian Basin province. At the surface, it consists of a mountainous to hilly area, whose main components are the Blue Ridge Mountains that extend from Georgia to Pennsylvania, including Mount Mitchell, the highest point east of the Mississippi River. Surface rocks are mainly low-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 sedimentary rock.

The province is bounded on the north by the Appalachian basin, on the west by Paleozoic sedimentary rocks of the Valley and Ridge part of the Appalachian Basin Province (fig. 32), and on the south by Cretaceous and younger sedimentary rocks of the Gulf Coastal Plain. It is bounded on the east roughly by metamorphic rocks of the inner part of the Piedmont Province (133) east of the Blue Ridge Mountains. No oil or gas has been produced in the province; one play was defined and individually assessed, the Overthrust play (020).

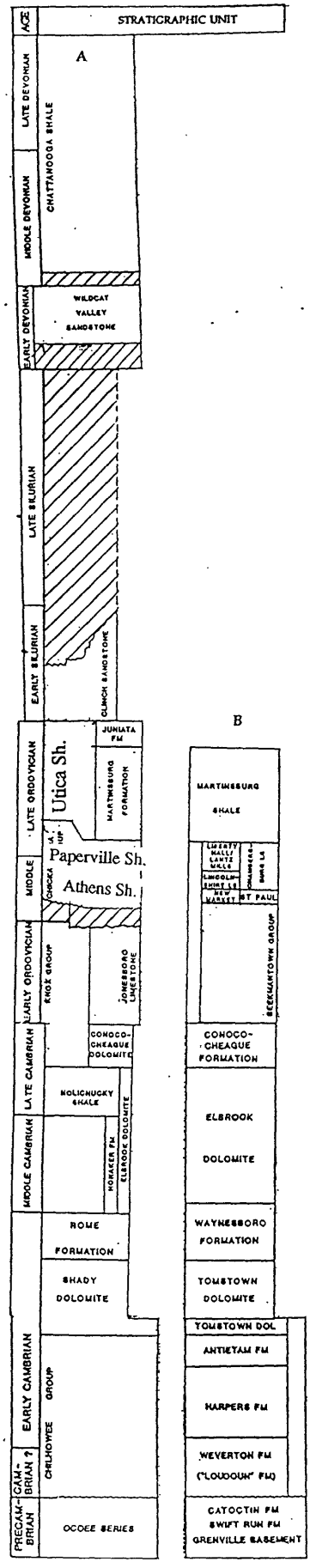

Figure 32. Generalized stratigraphic columns, Blue Ridge Thrust Belt province. A, Southern Appalachians, B, Central Appalachians.

OVERTHRUST PLAY (020)

The play is characterized by probable structural traps in Paleozoic strata in thrust sheets that are in turn buried beneath extensive thrust sheets of metamorphic and igneous rocks of the Blue Ridge. The play extends from Pennsylvania to Georgia and underlies mainly the Blue Ridge Mountains (fig. 33). The play is bounded on the west by outcropping Paleozoic rocks in the Valley and Ridge segment of the Appalachian Basin province and extends an undetermined distance eastward in the subsurface to the truncation of the Paleozoic sequence by a master basement thrust fault.

Fractured Cambrian and Ordovician carbonate rocks of the Knox Group and equivalents are reservoirs for the play. Fracture porosity is paramount. Seismic mapping in the central Appalachian basin show gas-productive, fracture porosity reservoirs in the Oriskany play (090, Province 131) in certain producing fields that are similar to the suspected reservoirs in structures in the Overthrust play.

Source beds are dark gray to black, basinal-derived Ordovician shales of the Appalachian basin such as the Utica (Martinsburg), Paperville, or Athens, which range in thickness from 200 to more than 2,000 ft. Thermal maturity ranges from the dry gas generation zone in the Appalachian basin eastward, to a supermature stage beneath the Blue Ridge.

Complex structures formed during the Paleozoic terminal Allegany orogeny would be available to trap gas that had been generated in deeply buried Ordovician source rocks. Seismic data interpretation shows abundant structural traps throughout the play. Drilling depths to potential Paleozoic reservoirs will range from about 4,000 ft along the play's west edge to more than 20,000 ft in its central part.

No wells have been drilled under the Blue Ridge Mountains from Pennsylvania to Georgia; the play is a high-risk exploration frontier with a fair future potential for small-size gas accumulations. However, a number of limiting factors, including 1) a rough mountainous terrain, 2) great drilling depths through hard and structurally complex strata to potential reservoirs, and 3) the difficulty of locating extensive fracture porosity zones beneath the allochthonous Blue Ridge thrust sheets will inhibit exploration in much of the play.

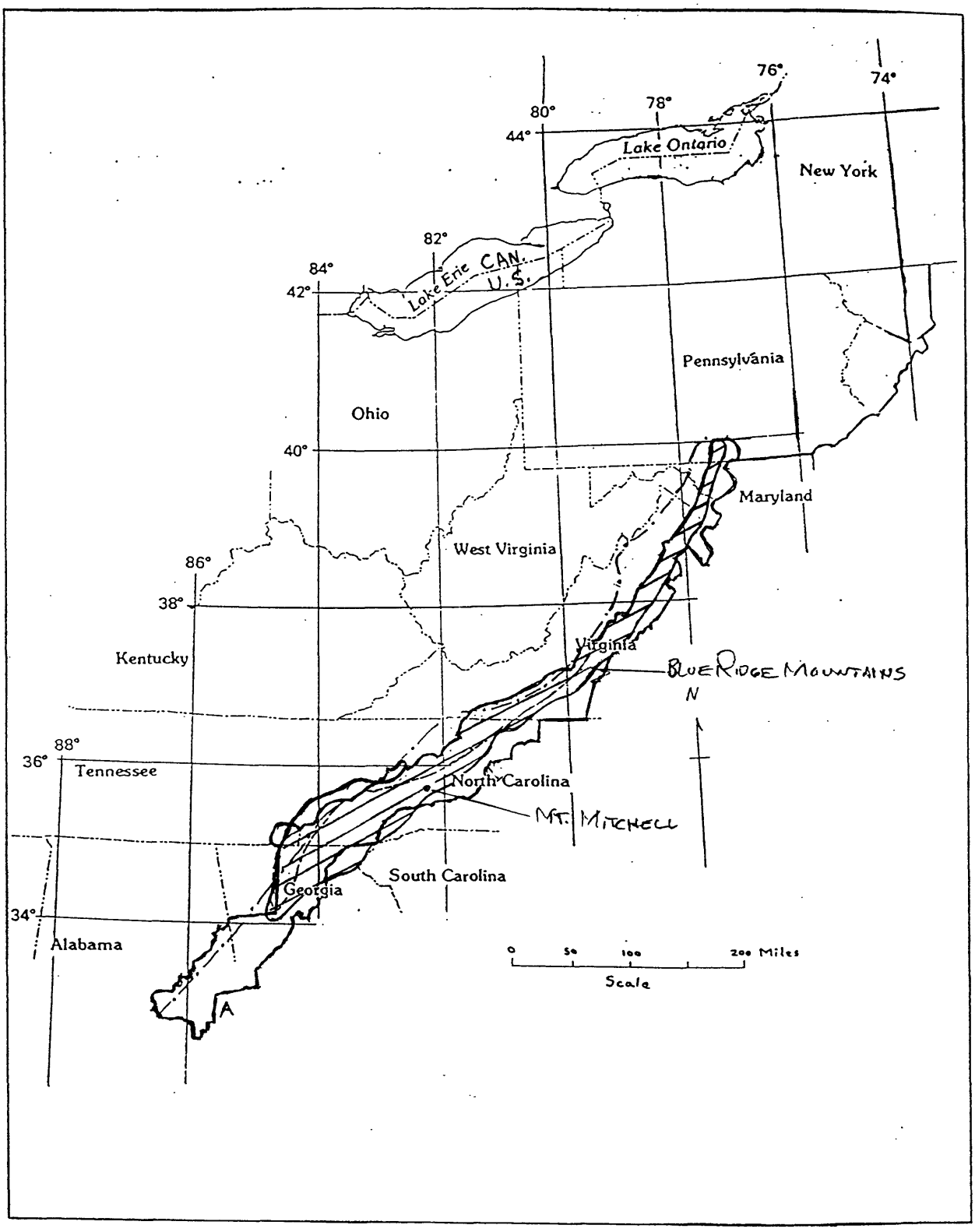

Figure 33. Map of Overthrust play.

OIL AND GAS PLAY DATA

PLAY **OVERTHRUST**
PROVINCE **BLUE RIDGE THRUST BELT** CODE **08-132-020**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assesed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**0**
Gas	**1**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gas (x 10^9 CFG)	**6**	**6.7**	**11**	**20**	**40**	**175**	**1000**
Reservoir depth (x10^3 ft)							
Oil	**0**			**0**			**0**
Gas (non-associated)	**8**			**12**			**25**
Number of accumulations	**5**	**6**	**8**	**10**	**14**	**22**	**30**

Average ratio of associated-dissolved gas to oil (GOR)	**0**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

PIEDMONT PROVINCE (133)

NEW ENGLAND-ADIRONDACK PROVINCE (134)
(Included under 133)

By Robert C. Burruss

INTRODUCTION

Assessment of undiscovered resources in the Piedmont province also includes assessment of the undiscovered resources of the New England-Adirondack province (134) and a part of the Atlantic Coastal Plain province (135). These undiscovered petroleum resources of these provinces are assessed in a single collective play, the Mesozoic Rift Basins play (020), that is common to all three of these provinces and in some cases extends beyond these province boundaries into the Blue Ridge Thrust Belt province (132) and the Florida Peninsula province (136). Fluvial and lacustrine rocks in the various rift basins belong to the Newark Supergroup, which ranges from Middle Triassic to Lower Jurassic in age and from 1,000 to about 20,000 ft in thickness (fig. 34). Because of very limited drilling and seismic exploration, and the minimal amount of petroleum geologic information, it was concluded that the assessment and discussion of a single common play in the three main provinces under province 133, and two adjacent provinces was appropriate.

The surficial regional geology of the Piedmont province consists of a variety of sharply folded and faulted supracrustal metasedimentary and plutonic intrusive rocks that are younger than the 880-1,000 million year old rocks of the Blue Ridge Thrust province to the west. In addition, there are thick sections of sedimentary and metasedimentary Triassic rocks containing intruded mafic igneous rocks. Metasediments within the Piedmont province may be as young as Ordovician. These Precambrian through lower Paleozoic rocks extend to the east under the Upper Jurassic through Cenozoic sediments of the Atlantic Coastal Plain province. Rift basins located partly or entirely within the Piedmont province include the Newark-Gettysburg-Culpeper (2), Richmond (4), and Durham-Sanford (5) (fig. 35). The province is non-productive of hydrocarbons.

The New England-Adirondack province (134) includes sedimentary, metasedimentary, and plutonic igneous rocks, mainly of Cambrian-Ordovician age, similar to rocks in the Blue Ridge (132) and Piedmont (133) provinces to the south. The uplifted, nearly circular Adirondack Mountains consist mainly of Precambrian rocks 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 the province. The greater part of one rift basin, the Hartford-Deerfield (1, fig. 35), is located in the province.

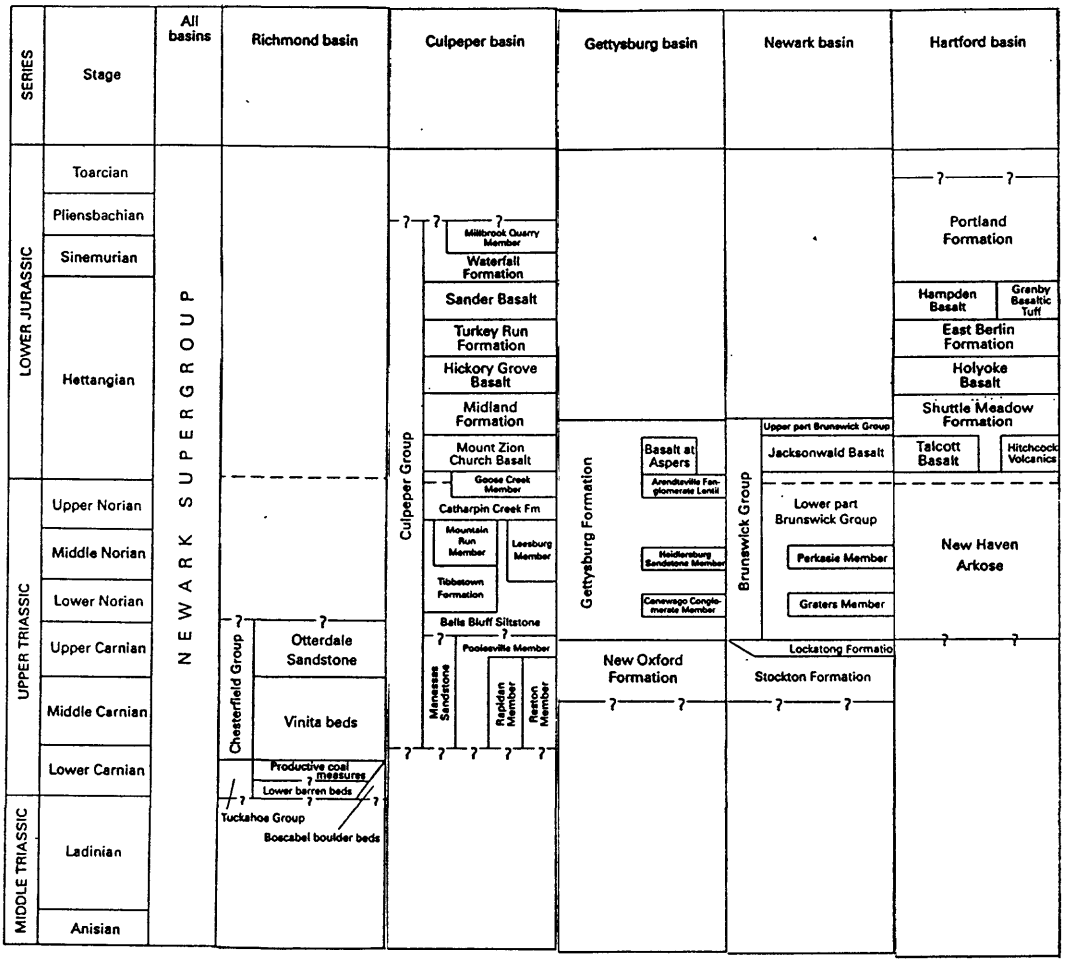

Figure 34. Generalized Mesozoic stratigraphic columns for the Piedmont, New England-Adirondack and Atlantic Coastal Plain provinces.

MESOZOIC RIFT BASINS PLAY (020)

This speculative play consists of a series of exposed and buried rift basins containing sediments of Triassic and Jurassic age where hydrocarbons may be trapped in structures or in stratigraphic pinchouts. These rift features occur within the Precambrian and Paleozoic metamorphic and igneous rocks that form the basement of the Piedmont (133), New England-Adirondack (134), Atlantic Coastal Plain (135), and Florida Peninsula (136) provinces of the eastern United States (fig. 35). The parts of these provinces relevant to the play include the states of Florida, Georgia, South Carolina, North Carolina, Virginia, Maryland, Delaware, Pennsylvania, New Jersey, Connecticut, and Massachusetts. Several commonly known rift basins are the Hartford-Deerfield basin of Connecticut and Massachusetts, the Newark basin of New Jersey and eastern Pennsylvania, the Taylorsville basin of Virginia, and the Durham-Sanford basin of North Carolina (fig. 35).

Although hydrocarbon shows have been reported from drill holes, there are no known economic reservoir rocks in any of the individual rift basins. Potential reservoirs occur throughout the stratigraphic section in fluvial and lacustrine rocks of the Upper Triassic Carnian Series to lacustrine sediments of the Lower Jurassic Toarcian Series (fig. 34). The quality of sandstone reservoirs is limited by extensive diagenesis and cementation in sedimentologically immature fluvial and lacustrine sediments. However, reservoir quality may be enhanced by fracturing associated with regional tilting and uplift of the individual rift basins.

The best potential source rocks are Lower Jurassic lacustrine black shales that contain up to 11 percent of mostly oil-prone total organic carbon (TOC) in thin (a few inches) beds and average several percent TOC over several feet. These source rocks overly the greatest thickness of rift sediments of Upper Triassic age. Potential Triassic source rocks may locally contain 2-3 wt. percent TOC, but this organic matter is dominated by woody-coaly debris that is gas-prone. Rapid Upper Triassic sediment accumulation allowed sufficient burial for hydrocarbon generation to start as early as latest Triassic time. Generation in Lower Jurassic age source rocks may have been enhanced by a pulse of hydrothermal heating associated with basaltic intrusion and extrusion. There are adequate amounts of organic matter present to possibly generate accumulations of petroleum in those rift basins where sediments exposed at the surface such as in the Newark, Hartford, and Richmond basins, or tested by the drill in the Taylorsville basin, have been studied geochemically (fig. 35).

Anticipated traps are in fault blocks, unconformities, and stratigraphic pinchouts in the fluvial-deltaic systems associated with rift basin bounding faults. Shows of petroleum occurred in fluvial sandstones of Carnian age in three wells drilled in the Richmond basin in Virginia. Shows in the form of petroleum fluid inclusions in fracture filling and porefilling cements and oil stained pores and fracture surfaces occur in lacustrine sediments and altered basalts of Hettangian age in the Newark and Hartford basins. Reservoir seals are difficult to identify. However, shale and mudrocks interbedded with Upper Triassic lacustrine and fluvial-deltaic sandstones may be important as seals. Altered basalts may have some potential as seals where they are not highly fractured. Also, faults may have some seal capacity in some basins. It is unlikely that the relatively coarse-grained upper Mesozoic and Cenozoic sediments that unconformably overly the buried rift basins in the Atlantic Coastal Plain province can provide any seal capacity.

Because of the complex geologic history of these rift basins and the lack of success in very limited exploration experience (less than 50 exploration drill holes in all basins in all provinces) it was concluded that qualitatively, the future potential for undiscovered hydrocarbon resources in the play is low.

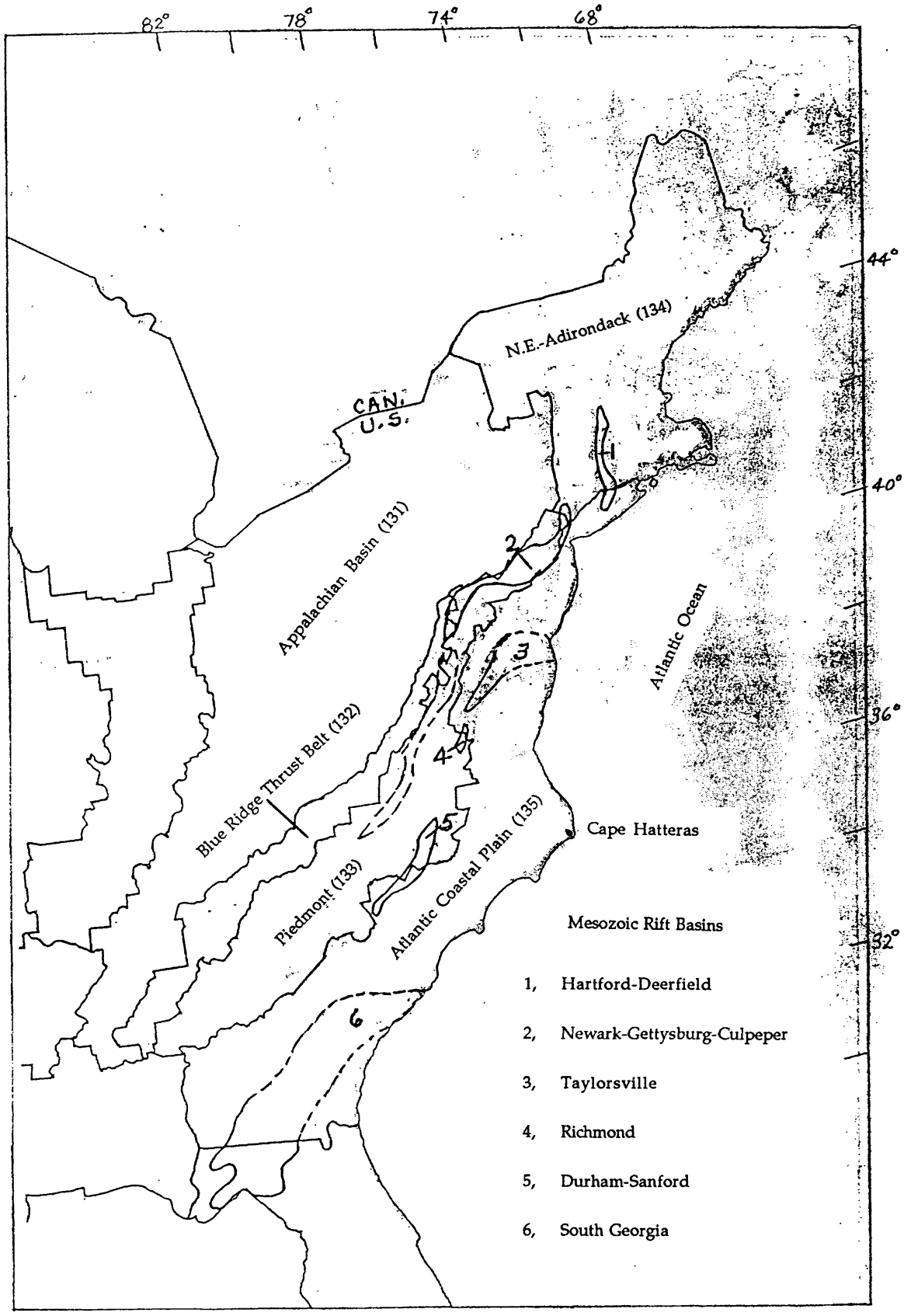

Figure 35. Map showing Mesozoic Rift Basins play within the Piedmont, New England-Adirondack, and Atlantic Coastal Plain provinces.

OIL AND GAS PLAY DATA

PLAY **MESOZOIC RIFT BASINS**
PROVINCE **PIEDMONT (133), NE ADIRON. (134), ATL. COASTAL PLAIN (135)** CODE **08-133-020**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assessed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	**X**
Carbonate rocks	
Other	
Hydrocarbon type	
Oil	**0.7**
Gas	**0.3**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.03**	**1.2**	**1.5**	**2.4**	**7.3**	**30**
Gas (x 10^9 CFG)	**6**	**6.2**	**7.2**	**9**	**13**	**25**	**75**
Reservoir depth (x10^3 ft)							
Oil	**3**			**6**			**15**
Gas (non-associated)	**3**			**6**			**15**
Number of accumulations	**1**	**3**	**7**	**10**	**14**	**22**	**30**

Average ratio of associated-dissolved gas to oil (GOR)	**800**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

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(134) New England-Adirondack
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TABLE 1.--Region 8 Eastern Interior. Estimates of undiscovered recoverable conventional oil gas, and natural gas liquids (NGL) in onshore provinces by play. Province and region totals are given.

[Mean value totals may not be equal to the sums of the component means because numbers have been independently rounded. Fractile values (F_{95}, F_5) are not additive and represent estimates with a 19 in 20 chance and a 1 in 20 chance, respectively, of at least these tabulated estimates. Gas includes both nonassociated and associated-dissolved gas. Negl., negligible quantity; -, no estimate.]

			Crude Oil (Millions of Barrels)			Total Gas (Billions of Cubic Feet)			NGL (Millions of Barrels)		
			F_{95}	F_5	Mean	F_{95}	F_5	Mean	F_{95}	F_5	Mean
127	Michigan Basin										
	020	Offshore Devonian Anticlinal	23.3	151.3	69.8	23.3	151.3	69.8	1.2	7.6	3.5
	030	Onshore Devonian Anticlinal	14.0	54.0	29.9	14.0	54.0	29.9	0.7	2.7	1.5
	040	Trenton-Black River	11.2	110.0	44.7	22.4	220.1	89.4	1.5	14.3	5.8
	050	So. Onshore Niagaran Reef	74.9	252.1	147.1	643.7	1,867.5	1,155.4	16.1	47.2	29.1
	060	No. Onshore Niagaran Reef	30.5	105.4	60.9	161.8	528.8	312.1	5.1	15.8	9.6
	070	Offshore Niagaran Reef	95.0	324.1	188.1	579.9	1,803.6	1,085.4	16.7	52.2	31.3
	080	Prairie du Chien	0.0	0.0	0.0	725.3	2,728.9	1,525.7	9.1	34.1	19.1
	090	Cambrian	0.0	0.0	0.0	0.0	2,617.0	693.0	0.0	32.7	8.7
	320	Oil <1 MMB	414.4	626.0	513.4	621.6	939.1	770.1	37.3	56.3	46.2
	330	Gas <6 BCF	0.0	0.0	0.0	1,641.0	2,503.8	2,043.8	24.6	37.6	30.7
		Province Total	631.2	1,620.7	1,053.8	3,924.1	13,400.0	7,774.5	103.0	300.1	185.4
128	Illinois Basin										
	020	Post-New Albany	12.5	52.9	28.3	12.5	52.9	28.3	0.3	1.3	0.7
	030	Silurian-Devonian Carbonate	8.6	77.9	32.2	8.6	77.9	32.3	0.2	1.9	0.8
	040	Silurian Reef	8.0	36.5	19.0	8.0	36.5	19.0	0.2	0.9	0.5
	050	Rough Creek Graben	0.0	0.0	0.0	0.0	517.3	61.9	0.0	5.2	0.6
	060	Mississippi Embayment	0.0	0.0	0.0	0.0	357.4	44.3	0.0	0.4	Negl.
	300	Other Occurrences >1 MMBO	9.1	46.5	23.3	9.1	46.5	23.3	0.2	1.2	0.6
	310	Other Occurrences >6 BCFG	0.0	0.0	0.0	24.1	88.0	49.8	0.4	1.3	0.7
	320	Oil <1 MMB	278.1	453.6	359.1	278.1	453.6	359.1	7.0	11.3	9.0
	330	Gas <6 BCF	0.0	0.0	0.0	29.6	53.7	40.5	0.4	0.8	0.6
		Province Total	302.4	666.5	462.1	162.7	1,631.5	658.5	6.5	24.2	13.6

TABLE 1.--Region 8 Eastern Interior. Estimates of undiscovered recoverable conventional oil gas, and natural gas liquids (NGL) in onshore provinces by play. Province and region totals are given--Continued

			Crude Oil (Millions of Barrels)			Total Gas (Billions of Cubic Feet)			NGL (Millions of Barrels)		
			F_{95}	F_5	Mean	F_{95}	F_5	Mean	F_{95}	F_5	Mean
129	Cincinnati Arch										
	020	Unconformity	6.5	21.0	12.5	1.3	4.2	2.5	Negl.	0.1	0.1
	030	Trenton	12.6	76.7	36.1	9.5	55.2	26.5	0.2	1.2	0.6
	320	Oil <1 MMB	33.5	80.6	53.9	13.4	32.2	21.6	0.0	0.0	0.0
	330	Gas <6 BCF	0.0	0.0	0.0	49.6	129.2	83.5	0.0	0.0	0.0
		Province Total	50.8	178.4	102.4	72.4	221.0	134.0	0.2	1.3	0.6
130	Black Warrior Basin										
	020	Chesterian	0.0	5.8	2.0	356.1	1,113.4	668.6	1.8	5.6	3.4
	310	Other Occurrences >6 BCFG	0.0	0.0	0.0	47.4	256.3	125.8	0.2	1.3	0.6
	320	Oil <1 MMB	3.1	7.3	4.9	2.8	6.6	4.4	Negl.	0.1	Negl.
	330	Gas <6 BCF	0.0	0.0	0.0	336.2	608.5	459.8	1.7	3.0	2.3
		Province Total	2.9	13.3	6.9	727.9	1,983.3	1,258.6	3.7	10.0	6.4
131	Appalachian Basin										
	020	Rome Trough	0.0	0.0	0.0	0.0	303.8	80.8	0.0	3.0	0.8
	040	Knox Gas	0.0	0.0	0.0	203.7	1,563.8	683.8	5.1	39.1	17.1
	050	Knox Oil	10.4	38.6	21.7	5.2	19.3	10.9	0.2	0.8	0.4
	060	Lower Silurian Clastic	0.0	0.0	0.0	926.4	3,022.6	1,785.0	23.2	75.6	44.6
	070	Upper Devonian Clastic	0.0	0.0	0.0	377.7	1,305.0	753.8	9.4	32.6	18.8
	080	Trenton	0.0	0.0	0.0	279.8	1,547.3	753.1	7.0	38.7	18.8
	090	Oriskany	0.0	0.0	0.0	481.8	2,312.1	1,182.5	12.0	57.8	29.6
	300	Other Occurrences >1 MMBO	11.3	38.0	22.2	5.7	19.0	11.1	0.2	0.8	0.4
	320	Oil <1 MMB	59.5	172.4	106.8	29.8	86.2	53.4	1.2	3.4	2.1
	330	Gas <6 BCF	0.0	0.0	0.0	529.8	2,088.8	1,147.5	13.2	52.2	28.7
		Province Total	81.2	249.1	150.7	2,766.7	12,289.0	6,461.8	70.2	304.5	161.5

TABLE 1.--Region 8 Eastern Interior. Estimates of undiscovered recoverable conventional oil gas, and natural gas liquids (NGL) in onshore provinces by play. Province and region totals are given--Continued

		Crude Oil (Millions of Barrels)			Total Gas (Billions of Cubic Feet)			NGL (Millions of Barrels)		
		F_{95}	F_5	Mean	F_{95}	F_5	Mean	F_{95}	F_5	Mean
132	Blue Ridge Thrust Belt									
020	Overthrust	0.0	0.0	0.0	182.3	1,795.8	728.6	0.0	0.0	0.0
330	Gas <6 BCF	0.0	0.0	0.0	55.5	123.4	85.3	0.0	0.0	0.0
	Province Total	0.0	0.0	0.0	223.7	1,928.6	813.9	0.0	0.0	0.0
133	Piedmont									
020	Mesozoic Rift Basins	5.3	55.1	22.3	16.5	136.9	58.4	0.0	0.0	0.0
320	Oil <1 MMB	6.9	33.1	17.0	5.6	26.5	13.6	0.0	0.0	0.0
330	Gas <6 BCF	0.0	0.0	0.0	32.6	103.7	61.9	0.0	0.0	0.0
	Province Total	12.1	88.5	39.3	52.1	268.4	133.9	0.0	0.0	0.0
134	New England-Adirondack (Incl. in 133)									
	REGION TOTAL	1,308.3	2,430.9	1,815.2	10,764.0	25,726.0	17,235.1	230.6	546.5	367.4

REGION 9--ATLANTIC COAST

GEOLOGIC FRAMEWORK

By Richard B. Powers

Region 9 contains two provinces, 135 and 136 (fig. 36), and two individually assessed plays. One of these, the regionally extensive Mesozoic Rift Basins play, covers areas in three provinces; Piedmont (133) and New England-Adirondack (134) in Region 8, and the Atlantic Coastal Plain (135) in Region 9. Resources in this play and a play map are included and discussed in the Piedmont province section.

The Atlantic Coast Region, which extends through peninsular Florida, embraces both early Mesozoic rift basins and an overlying wedge of younger rocks. Elongate, extensional rift basins containing Upper Triassic and Lower Jurassic rocks of nonmarine origin are found exposed in the Appalachian Piedmont from Georgia to northern Massachusetts and are inferred to occur beneath coastal plain sediments. Sedimentary rocks of the coastal plain that cover these basins include largely terrigenous clastics and marine carbonates of late Mesozoic, Cenozoic, and Holocene age. From north to south, these younger rocks become increasingly carbonate rich; south of the Peninsular Arch in Florida, the sediment wedge becomes almost exclusively carbonate and anhydrite and thickens into the South Florida basin.

Although a small amount of oil has been found in the South Florida basin, oil production has not been established elsewhere in the region, and the Atlantic Coastal Plain generally appears to have little future petroleum potential.

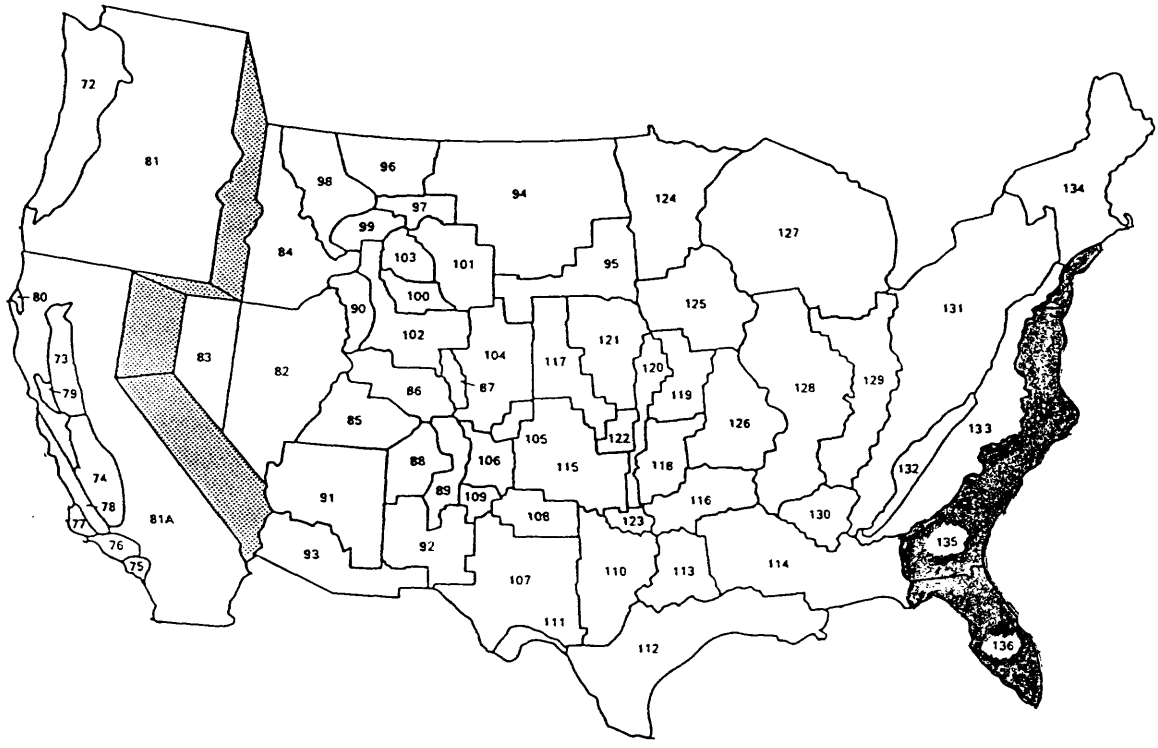

Figure 36. Index map of lower 48 states showing provinces assessed in Region 9 (shaded).

Names of provinces are listed by number in table of estimates.

ATLANTIC COASTAL PLAIN PROVINCE (135)

By Robert C. Burruss and Jan Libby-French

The province covers an area of approximately 383, 400 mi^2 and includes portions of the States of Georgia, South Carolina, North Carolina, Virginia, Maryland, Delaware, New Jersey, and New York (Long Island) (fig. 35). Sedimentary rocks of the coastal plain dip and thicken seaward in the area between the Piedmont province (133) and the Atlantic Ocean, and overlie igneous and metamorphic basement rocks of Paleozoic and Precambrian age. Post-Paleozoic warping of basement rocks resulted in a series of embayments and arches along the coast. Both clastic and carbonate rocks of Triassic through Cenozoic age make up the sedimentary section above the basement; this sequence ranges in thickness from zero at the western edge of the coastal plain to slightly more than 10,000 ft at Cape Hatteras, North Carolina. Clastic rocks of Upper Jurassic through Cenozoic age are present throughout the province; carbonate rocks of Cretaceous through Cenozoic age are restricted to the southern portion of the coastal plain.

Triassic red beds and intrusive igneous rocks are present in a series of exposed and buried rift basins whose extent is incompletely known. Some have been delineated by seismic studies, and some have been approximately located by well drilling. All or parts of six of these rift basins are located in the Atlantic Coastal Plain province (fig. 35) and are included in the Mesozoic Rift Basins play which is discussed in the preceeding section on the Piedmont province. There is no production of hydrocarbons in the province.

FLORIDA PENINSULA PROVINCE (136)

By Mahlon M. Ball

INTRODUCTION

The province includes all of the State of Florida with the exception of the western part of the Florida panhandle. Including State waters, the province is approximately 150 mi in width and about 400 mi in length. State waters on the Gulf of Mexico side of Florida extend to 3 leagues (10.36 statute mi) and to 3 miles on the Atlantic Ocean side. The Gulf-Atlantic boundary line is along 83°W, west of the Dry Tortugas, and 24°35'N between the Dry Tortugas and Marquesas Key. The Peninsular arch and South Florida basin are the dominant major structural features. The arch is an igneous basement high plunging south-southeast along the axis of the northern half of the Florida peninsula. The South Florida basin contains as much as 20,000 ft of Cenozoic and Mesozoic, predominantly carbonate, rocks in southwesternmost Florida (fig. 37). Since the first oil discovery in the province in 1943, cumulative production from 14 fields to 1987 was approximately 80 MMBO and 6.8 BCFG. One play was defined and individually assessed in the province, the Sunniland Carbonate play (020) in the South Florida basin.

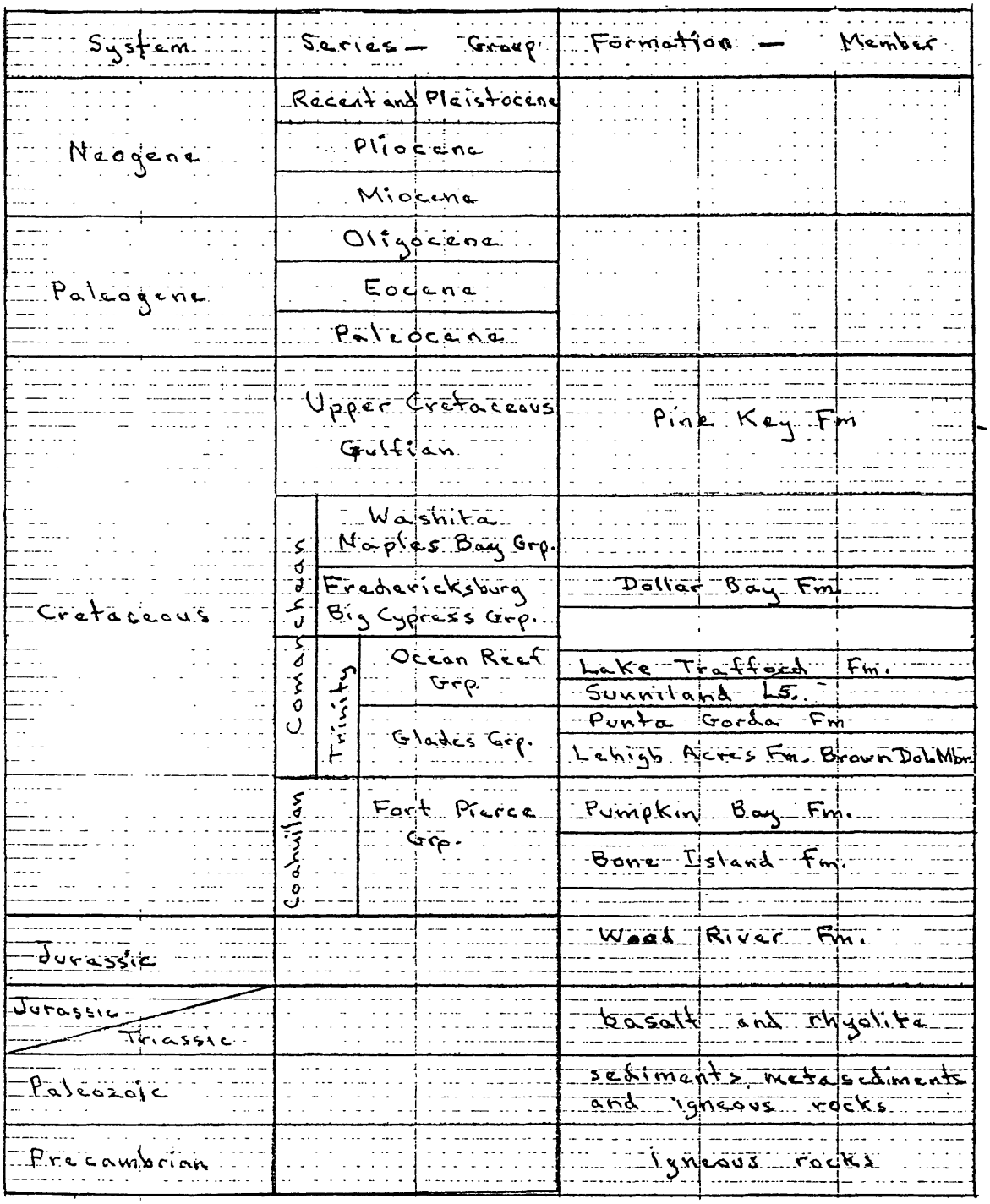

Figure 37. Generalized stratigraphic column, Florida Peninsula province.

SUNNILAND CARBONATE PLAY (020)

The play involves stratigraphic traps in patch reef mounds in the Sunniland Limestone of Early Cretaceous age (Comanchean) in the South Florida basin along an arc, or fairway, about 175 mi long and 20 mi wide. The play covers a total area of approximately 3,500 mi^2 and extends offshore into State waters at the 3-league limit of Federal-State waters in the Gulf of Mexico (fig. 38). Regional structure is a low angle dip (20 ft per mi) toward the southwest. The limits of the fairway are controlled by porosity and permeability reduction in the Sunniland Limestone both up-dip and down-dip.

Overall total thickness of the Sunniland is about 250 ft, and reservoir pay thicknesses are measured in the tens of feet; these occur at or near the top of the Sunniland. Reservoirs are dolomitized, bioclastic, algal-rudistid patch reefs. Average porosity is 20 percent and average permeability is 60 millidarcies; maximum reported porosity is 28 percent and maximum reported permeability is 665 millidarcies. Both primary and secondary porosity are important in reservoir development. Seals are anhydrite beds in the overlying Lake Trafford Formation (fig. 37).

Because the Sunniland is sandwiched between massive anhydrite beds of regional extent and contains dark-colored, organic-rich carbonates in the lower part of the unit, the source of the oil is believed to be of local origin. Oil fields, to date, have been found only where organic-rich carbonate rocks make up 30 to 60 percent of the Sunniland interval. Pyrolized hydrocarbons from these dark-colored carbonates match geochemically the immature hydrocarbons in Sunniland reservoirs. Immaturity of source rocks is believed to be the reason for the low gas-oil ratio of Sunniland oil (GOR : 85 CF/BO). Traps are primarily stratigraphically controlled and consist of patch reef mounds with closures of a few tens of feet. The largest known areal extent of a patch reef is about 15 mi^2.

The Sunniland oil field was discovered in 1943 and the last reported field discovery was in 1985. Fourteen fields have been found in the play trend. Total ultimate recovery from the overall trend is estimated to be about 100 MMBO. The largest field, West Felda, is about 50 MMBO in size, and four other fields have recoveries that exceed 10 MMBO. Depth to production ranges from 11,000 to 12,000 ft.

The future potential of the play is moderate and limited by the relatively small onshore area of the play within the province. The largest part of the play area lies in its projection into Federal waters in the Gulf of Mexico.

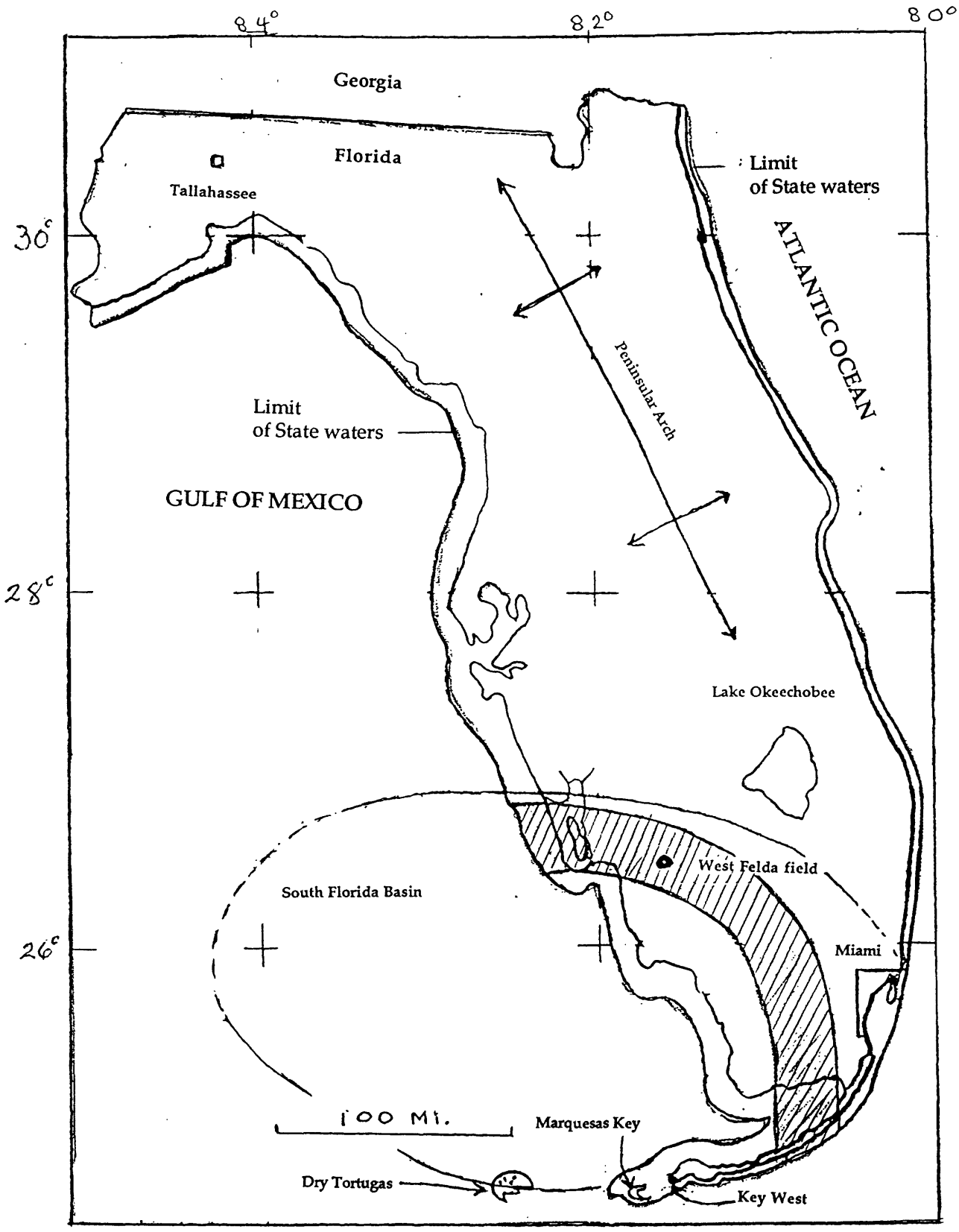

Figure 38. Map of Sunniland Carbonate play.

OIL AND GAS PLAY DATA

PLAY **SUNNILAND CARBONATE**
PROVINCE **FLORIDA PENINSULA** CODE **09-136-020**

Play attributes

	Probability of attribute being favorable or present
Hydrocarbon source (S)	**1.00**
Timing (T)	**1.00**
Migration (M)	**1.00**
Potential reservoir-rock facies (R)	**1.00**
Marginal play probability (MP) (S x T x M x R = MP)	**1.00**

Accumulation attribute, conditional on favorable play attributes

Minimum size assessed: oil, 1 x 10^6 BBL; gas, 6 x 10^9 CFG

	Probability of occurrence
At least one undiscovered accumulation of at least minimum size assesed	**1.00**

Character of undiscovered accumulations, conditional on at least one undiscovered accumulation present

Reservoir lithology	Probability of occurrence
Sandstone	
Carbonate rocks	**X**
Other	
Hydrocarbon type	
Oil	**1**
Gas	**0**

	Fractiles * (estimated amounts)						
Fractile percentages * ----	*100*	*95*	*75*	*50*	*25*	*5*	*0*
Accumulation size							
Oil (x 10^6 BBL)	**1**	**1.3**	**2.6**	**5.7**	**14**	**60**	**290**
Gas (x 10^9 CFG)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Reservoir depth (x10^3 ft)							
Oil	**11**			**11.5**			**12**
Gas (non-associated)	**0**			**0**			**0**
Number of accumulations	**5**	**6**	**8**	**10**	**13**	**17**	**20**

Average ratio of associated-dissolved gas to oil (GOR)	**85**	CFG/BBL
Average ratio of NGL to non-associated gas	**0**	BBL /10^6 CFG
Average ratio of NGL to associated-dissolved gas	**0**	BBL /10^6 CFG

* For example, fractile percentage 95 represents a 19 in 20 chance of the occurrence of at least the fractile tabulated.

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TABLE 2.--Region 9 Atlantic Coast. Estimates of undiscovered recoverable conventional oil gas, and natural gas liquids (NGL) in onshore provinces and adjacent State waters, by play. Province and region totals are given.

[Mean value totals may not be equal to the sums of the component means because numbers have been independently rounded. Fractile values (F_{95}, F_5) are not additive and represent estimates with a 19 in 20 chance and a 1 in 20 chance, respectively, of at least these tabulated estimates. Gas includes both nonassociated and associated-dissolved gas. Negl., negligible quantity; -, no estimate.]

		Crude Oil (Millions of Barrels)			Total Gas (Billions of Cubic Feet)			NGL (Millions of Barrels)		
		F_{95}	F_5	Mean	F_{95}	F_5	Mean	F_{95}	F_5	Mean
135	Atlantic Coastal Plain (Incl. with 133)									
136	Florida Peninsula									
020	Sunniland Carbonate	57.1	484.7	205.5	4.9	41.2	17.5	0.0	0.0	0.0
320	Oil <1 MMB	5.0	13.1	8.4	0.4	1.1	0.7	0.0	0.0	0.0
	Province Total	61.1	498.4	213.9	5.2	42.4	18.2	0.0	0.0	0.0
	REGION TOTAL	61.1	498.4	213.9	5.2	42.4	18.2	0.0	0.0	0.0