U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Possible continuous-type (unconventional) gas accumulation in the Lower Silurian "Clinton" sands, Medina Group, and Tuscarora Sandstone in the Appalachian basin: A progress report of 1995 project activities

Robert T. Ryder[1], Kerry L. Aggen[2], Robert D. Hettinger[2], Ben E. Law[2], John J. Miller[2], Vito F. Nuccio[2], William J. Perry, Jr.[2], Stephen E. Prensky[2], John R. SanFilipo[1], and Craig J. Wandrey[2]

Open-File Report 96-42

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

1 U.S. Geological Survey, Reston, Virginia 22092
2 U.S. Geological Survey, Denver, Colorado 80225

CONTENTS

ILLUSTRATIONS

TABLES

APPENDICES

INTRODUCTION

In the U.S. Geological Survey's (USGS) 1995 National Assessment of United States oil and gas resources (Gautier and others, 1995), the Appalachian basin was estimated to have, at a mean value, about 61 trillion cubic feet (TCF) of recoverable gas in sandstone and shale reservoirs of Paleozoic age. Approximately one-half of this gas resource is estimated to reside in a regionally extensive, continuous-type gas accumulation whose reservoirs consist of low-permeability sandstone of the Lower Silurian "Clinton" sands and Medina Group (Gautier and others, 1995; Ryder, 1995). Recognizing the importance of this large regional gas accumulation for future energy considerations, the USGS initiated in January 1995 a multi-year study to evaluate the nature, distribution, and origin of natural gas in the "Clinton" sands, Medina Group sandstones, and equivalent Tuscarora Sandstone. The project is part of a larger natural gas project, Continuous Gas Accumulations in Sandstones and Carbonates, coordinated in FY1995 by Ben E. Law and Jennie L. Ridgley, USGS, Denver. Approximately 2.6 man years were devoted to the Clinton/Medina project in FY1995.

A continuous-type gas accumulation, referred to in the project, is a new term introduced by Schmoker (1995a) to identify those natural gas accumulations whose reservoirs are charged throughout with gas over a large area and whose entrapment does not involve a downdip gas-water contact. Gas in these accumulations is located downdip of the water column and, thus, is the reverse of conventional-type hydrocarbon accumulations. Commonly used industry terms that are more or less synonymous with continuous-type gas accumulations include basin-centered gas accumulation (Rose and others, 1984; Law and Spencer, 1993), tight (low-permeability) gas reservoir (Spencer, 1989; Law and others, 1989; Perry, 1994), and deep basin gas (Masters, 1979, 1984).

The realization that undiscovered gas in Lower Silurian sandstone reservoirs of the Appalachian basin probably occurs in a continuous accumulation rather than in conventionally trapped, discrete accumulations represents a significant departure from the 1989 National Assessment (Mast and others, 1989; deWitt, 1993). In 1989, a direct assessment (field-size distributions required for play analysis were unavailable) of the Lower Silurian sandstone play gave, at a mean value, about 1.7 TCF of gas. The 1995 estimate (~30 TCF of gas) is so much greater than the 1989 estimate (~1.7 TCF of gas) because of the interpreted continuous nature of the accumulation and the assessment methodology applied. The methodology for continuous hydrocarbon accumulations assumes that the reservoirs in the accumulation are gas-saturated and takes into account: 1) estimated ultimate recovery (EUR) per well probability distributions, 2) optimum area that a well can drain (spacing), 3) number of untested drill sites having the appropriate spacing area, 4) success ratio of previously drilled holes, and 5) risk (Schmoker, 1995b).

Davis (1984), Zagorski (1988, 1991), and Law and Spencer (1993) were among the first petroleum geologists to suggest that gas in the "Clinton" sands and Medina Group sandstones was trapped in a basin-centered/deep basin accumulation. They recognized many of the earmarks of a basin-centered/deep basin accumulation such as low-permeability reservoirs, abnormally low formation pressure, coalesced gas fields, gas shows or production in most holes drilled, low water yields, and a general lack of structural control on entrapment. Ryder (1995) adopted this interpretation by defining four continuous-type gas plays (6728-6731) in the "Clinton" sands-Medina Group interval (fig.1).

Play 6728 (Clinton/Medina sandstone gas high potential) covers a 17,000 sq mi region of western New York, northwestern Pennsylvania, eastern Ohio, and a small part of westernmost West Virginia that is very favorable for future gas resources (fig.1). Also, this play includes a large part of eastern Lake Erie. From the late 1970's to the present, this area has produced gas from drilling depths of about 2,500 to 4,500 ft in New York, 3,500 to 6,500 ft in Pennsylvania, and 5,000 to 6,500 in Ohio. A large part of play 6728 remains undrilled along its southeastern margin and in Lake Erie. Drilling depths are as great as 7,500 ft along the southeast margin of the play and between 1,500 and 2,500 ft in Lake Erie. Very likely, the entire undrilled part of the play contains gas-saturated "Clinton" sands and Medina Group sandstones. Most of the sandstone reservoirs are tight and require stimulation by hydrofracturing. In the 1980's and early 1990's, gas production from these tight reservoirs with permeability less than 0.1 milliDarcys (mD) was encouraged with price incentives administered by the Federal Energy and Regulatory Commission (FERC). Although plays 6729 through 6731 have potential for future gas resources they are less desirable than play 6728 because of thinner and probably lower quality reservoirs.

The Clinton/Medina sandstone gas plays are flanked by two additional plays that involve the Lower Silurian sandstone depositional system. The first play (Clinton/Medina sandstone oil/gas play--6732), marks an oil and gas producing region of east-central Ohio that is updip and transitional with the continuous gas plays (Ryder,1995)(fig.1). It closely corresponds to Area 1 (oil and gas in Clinton sands of Ohio) of the Lower Silurian sandstone play of deWitt (1993). Ryder (1995) considers play 6732 to be a conventional oil and gas play because of its tendency to have discrete accumulations with well-defined oil- and gas-water contacts. Oil and gas have been produced in this play since the early 1880's and are

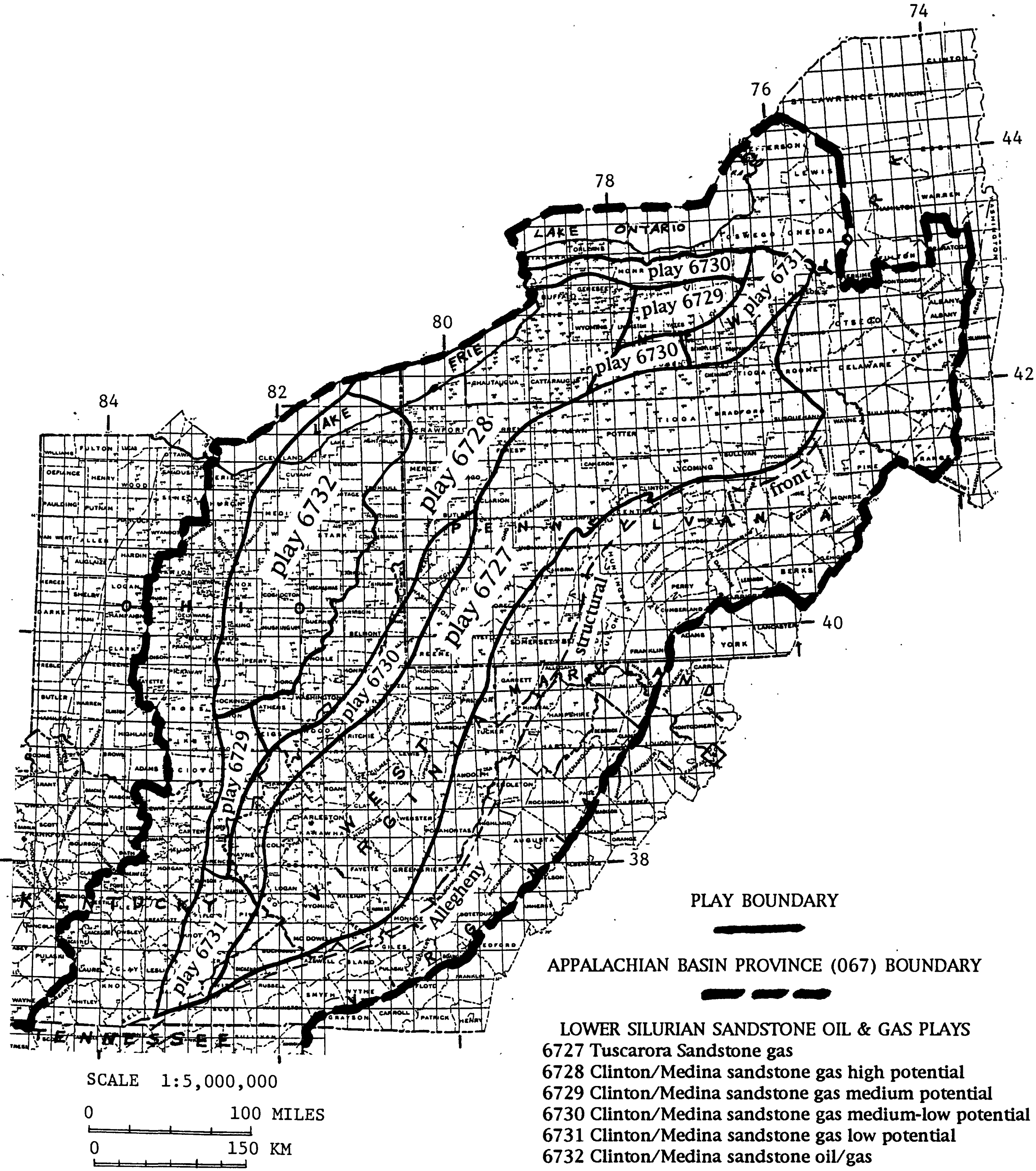

Figure 1. Map of the northern part of the Appalachian basin province (067) showing oil and gas plays in the Lower Silurian "Clinton" sands, Medina Group sandstones, and Tuscarora Sandstone.

now largely depleted except for the Lake Erie part. The second play, (Tuscarora Sandstone gas play--6727), marks the approximate limit of undiscovered gas in basement-controlled anticlines and combination traps in the Tuscarora Sandstone, a more proximal, sandstone-dominated facies of the Lower Silurian clastic wedge (Ryder, 1995)(fig. 1). This play extends eastward from a transitional boundary with the Clinton/Medina sandstone gas plays to near the Allegheny structural front (fig. 1). Ryder (1995) classified the Tuscarora Sandstone gas play as a conventional gas play because its scattered gas accumulations seem to be largely controlled by anticlinal structures and have well-defined gas-water contacts.

OBJECTIVES AND RESEARCH STRATEGY

The main objective of this project is to establish geologic controls and pressure/temperature conditions of the regional Clinton/Medina gas field. From these attributes, we should gain a better understanding of the field and be able to evaluate whether or not it is correctly classified as a continuous-type gas accumulation. Similar controls and conditions will be examined for the Tuscarora Sandstone reservoir and its scattered gas fields to determine the feasibility of extending the continuous-type gas accumulation eastward and deeper into the basin. Additional objectives are: 1) to define the range of gas production per well throughout the accumulation and evaluate the geologic cause(s) of the production variability, in particular, production "sweet spots" in the accumulation, 2) to develop a model for gas generation and entrapment, and 3) to review, and revise if necessary, the methodology for assessing recoverable gas in the accumulation. We anticipate that the Clinton/Medina/Tuscarora(?) example may provide an assessment analog for similar gas accumulations in the United States and the World.

Topics to be addressed in detail include:

1) stratigraphic framework of Clinton/Medina/Tuscarora sandstones across parts of New York, Ohio, Pennsylvania, and West Virginia,

2) comparison of gas-well productivity (initial production and EUR) against variations in reservoir depth, reservoir thickness, and structural setting,

3) structure contour and drilling depth maps of the reservoir interval across the Clinton/Medina/Tuscarora sandstone play area,

4) downdip limits of oil and water production,

5) thermal maturation history of the Clinton/Medina/Tuscarora reservoirs based on conodont alteration indices (CAI) and burial, thermal, and petroleum generation models,
6) geochemistry and isotopic composition of natural gas in the Clinton/Medina/Tuscarora reservoirs and their bearing on the source, thermal maturity, and migration history of the gas,
7) role of fractures on gas productivity and the utility of seismic profiles and(or) geophysical log suites for their detection,
8) variation in formation pressure and temperature across the area of the Clinton/Medina/Tuscarora plays,
9) core and well log analysis to determine the degree of continuity of small-scale lithologically and(or) diagenetically controlled zones of high porosity and permeability in the sandstone reservoirs,
10) compilation of an oil and gas field map for the Clinton/Medina/Tuscarora reservoirs, and
11) environmental concerns such as land use and brine composition in regions of Clinton/Medina/Tuscarora gas production.

Given the large area involved, with thousands of wells, many of these planned topics of investigation will focus along regional transects oriented normal and parallel to the paleoshoreline and the present-day basin margin. Most of the transects are designed to be long enough so as to accommodate detailed comparisons between the proposed continuous-type gas accumulation of the Clinton/Medina sandstone gas play and adjoining accumulations of the Clinton/Medina sandstone oil/gas and Tuscarora Sandstone gas plays. Substantial computer support is required for storage and manipulation of data files and the construction of digital maps.

SANDSTONE CHARACTER AND DEPOSITIONAL SEQUENCES ALONG SELECTED TRANSECTS

Four transects were chosen to characterize the stratigraphic framework of the "Clinton" sands, Medina Group, Tuscarora Sandstone and adjoining units. Adjoining units include the Upper Ordovician Queenston Shale, Lower Silurian Clinton Group, and Lower and Upper Silurian Lockport Group. The Medina, Clinton, and Lockport Groups constitute the Niagaran Provincial Series. Three of the transects, B-B' (New York and Pennsylvania), C-C' (Pennsylvania and Ohio), and D-D' (Ohio and West Virginia), are between 120 and 185 mi long and trend northwest-southeast, approximately subparallel to the depositional dip of the Lower

Silurian sandstone system (fig.2). A 425-mi-long, northeast-southwest trending transect, A-A' (New York, Pennsylvania, and Ohio), is oriented approximately subparallel to the depositional strike of the Lower Silurian sandstone system and connects the three northwest-southeast trending transects (fig. 2). All transects are constructed with geophysical well logs, primarily of the gamma ray/density or gamma ray/neutron type. About 35 to 40 wells are used for each of the northwest-southeast transects and about 75 to 85 wells are used for the northeast-southwest transect. Regional sections shown in Cate(1965), Knight(1969), Piotrowski(1981), and numerous M.S. theses assisted correlations between many of the control points. In addition to detailed correlations of reservoir sandstone units and the overlying Reynales/Irondequoit/Packer Shell/Dayton carbonate units, the transects contain information such as production status of wells, perforated interval(s), type and amount of gas and(or) fluids produced, formation pressure, and bottom-hole temperature.

Transect B-B'

Transect B-B' extends roughly 40 miles across Chautauqua County, New York (fig. 3). The 80- to 90-mi-long Pennsylvania part of transect B-B' has not yet been completed. The N35°W-S35°E trend of the transect is oriented nearly perpendicular to paleoshoreline trends as interpreted from Lower Silurian Medina Group sandstones and the Tuscarora Sandstone by Cotter (1983). Rocks of the Medina Group dip southeastward across the transect and occur at depths of 2,260 to 2,420 ft at the northwest end of the transect and 4,480 to 4,640 ft at the southeast end. Geophysical logs from 43 drill holes, spaced approximately 1 mi apart, are used to correlate the Medina Group and adjoining strata. The drill holes are identified and located in table 1.

Type and reference sections for the Niagaran Provincial Series are described from exposures along the Niagara Escarpment, located 55-120 mi north and northeast of transect B-B'. Brett and others (1995) give an excellent historical stratigraphic overview of these rocks and provide stratigraphic revisions based on their own research. Sequence stratigraphic interpretations for the Niagaran Series are provided by Brett and others (1990). Stratigraphic nomenclature, lithologic descriptions, and rock ages of the Niagaran Series, as used in this discussion, are based primarily on Brett and others (1990, 1995) and are summarized in table 2. Additional lithologic descriptions of the Medina Group are provided by Laughrey (1984) from drill-hole core about 40 mi west of the transect in northwestern Pennsylvania.

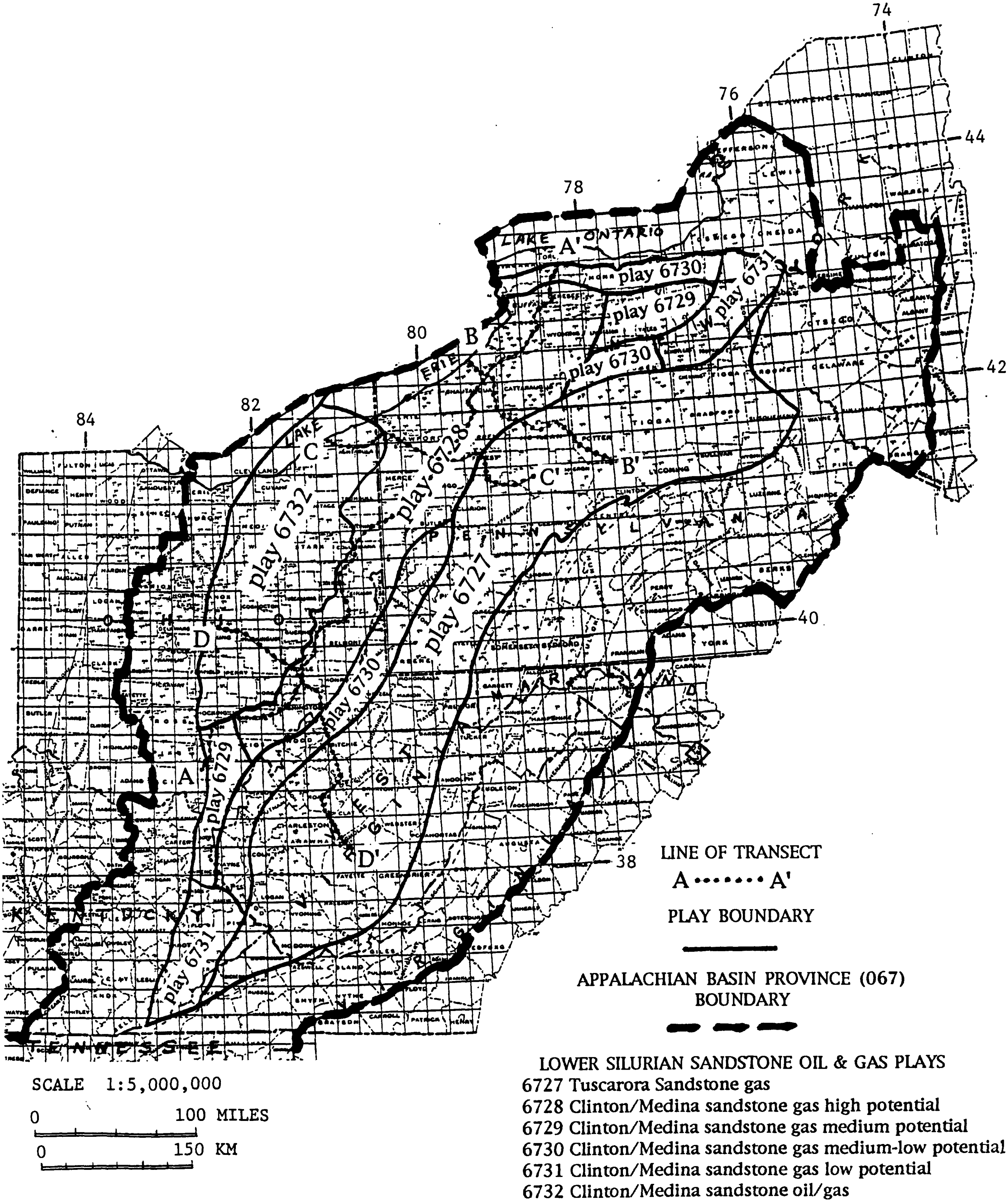

Figure 2. Map of the northern part of the Appalachian basin province (067) showing oil and gas plays in Lower Silurian sandstones and lines of transects.

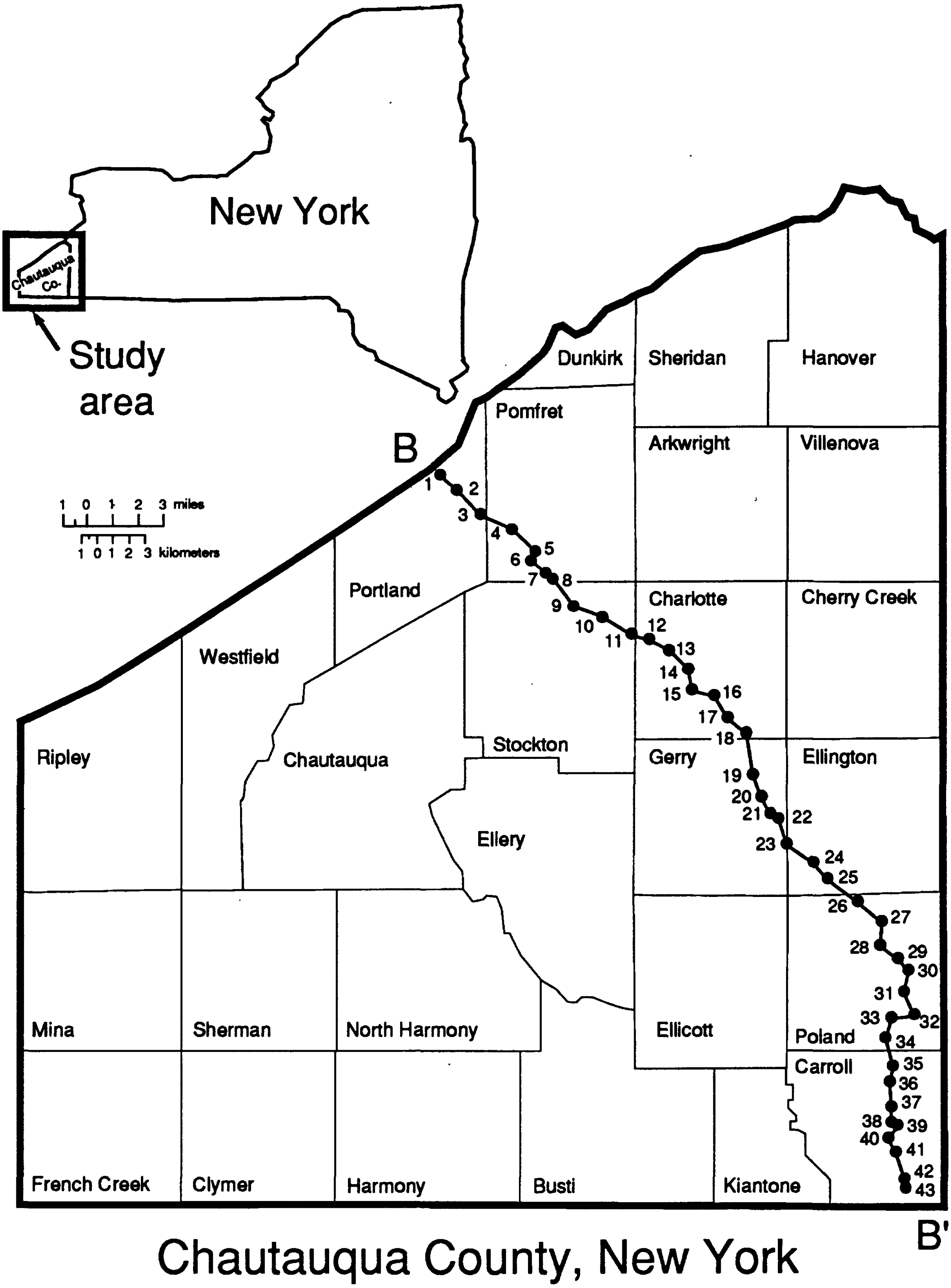

Figure 3. Map of Chautaqua County, New York, showing locations and identification numbers of drill holes used in transect B-B'. Drill hole numbers also apply to table 1 and figures 4 and 5.

Map #	API Number	Company	Well Number	Township
1	31-013-10528	Flint Oil & Gas, Inc.	Hayes #16 #1127	Portland
2	31-013-10534	Flint Oil & Gas, Inc.	Cliffstar #2	Portland
3	31-013-12133	Flint Oil & Gas, Inc.	#1252-Szymczak Unit #1	Portland
4	31-013-11540	Flint Oil & Gas, Inc.	C. Lanford #1-1239	Pomfret
5	31-013-10460	Paragon Res., Inc.	Willis Snell #1 Unit 60	Pomfret
6	31-013-10461	Paragon Res., Inc.	R. Hancock Unit 59 #1	Pomfret
7	31-013-10298	Paragon Res., Inc.	Paul Crowe, Jr., Unit 63 #1	Pomfret
8	31-013-10479	Paragon Res., Inc.	Goot #1 Unit 68	Pomfret
9	31-013-11205	Paragon Res., Inc.	Joseph Mikula Unit 152 #1	Stockton
10	31-013-11373	Paragon Res., Inc.	Johnson Unit 334 #1	Stockton
11	31-013-11605	Paragon Res., Inc.	Albert Van Dette Unit 339 #1	Stockton
12	31-013-11913	Paragon Res., Inc.	Albert Van Dette Unit 439 #1	Charlotte
13	31-013-13273	Paragon Res., Inc.	#1 Munch-Ingalls Unit 546	Charlotte
14	31-013-18055	Univ. Res. Holding, Inc.	Saxton No. 5	Charlotte
15	31-013-18715	Dest Corp.	Strata Unit No. 2	Charlotte
16	31-013-16832	Univ. Res. Holding, Inc.	Newton Bros No. 4	Charlotte
17	31-013-16988	Univ. Res. Holding, Inc.	G. Drozdowski No. 1	Charlotte
18	31-013-18226	Templeton Energy, Inc.	G. Edson #1 (754)	Charlotte
19	31-013-15412	U.S. Energy Develop. Corp.	E. Olmsted No. 1	Gerry
20	31-013-15681	Univ. Res. Holding, Inc.	O. Olson No. 2	Gerry
21	31-013-19299	Empire Exploration	NYS Refore. Area 12	Gerry
22	31-013-19297	Empire Exploration	NYSRA 12, Unit 3#6396	Gerry
23	31-013-19027	Envirogas, Inc.	R. Hitchcock #1	Ellington
24	31-013-18243	Envirogas, Inc.	L. Beightol #1	Ellington
25	31-013-18345	Envirogas, Inc.	G. Colburn #1	Ellington
26	31-013-17943	Envirogas, Inc.	R. Dennison #1	Poland
27	31-013-18182	Envirogas, Inc.	R. Wilson #1	Poland
28	31-013-20005	Envirogas, Inc.	J. Riffell No. 1	Poland
29	31-013-19898	Envirogas, Inc.	L. Carlson #1	Poland
30	31-013-17957	Envirogas, Inc.	P. Pero #1	Poland
31	31-013-18002	Union Drilling Inc.	Mervel Anderson #1-4017	Poland
32	31-013-17692	Bounty Oil & Gas, Inc.	Sanders #1	Poland
33	31-013-17682	Bounty Oil & Gas, Inc.	Thompson #1	Poland
34	31-013-16443	Union Drilling, Inc.	D. Coe Sr. #NY-0003	Poland
35	31-013-15947	Doran & Assoc., Inc.	Minor No. 1	Carroll
36	31-013-17699	Doran & Assoc., Inc.	Littlefield No. 1 SN: KV37	Carroll
37	31-013-19701	Washakie Oil Co.	M.Morreale #1	Carroll
38	31-013-17827	Doran & Assoc., Inc.	C. Brown Unit No. 1 K-V-44	Carroll
39	31-013-17947	Doran & Assoc., Inc.	A. Carlson Unit #1 KV-46	Carroll
40	31-013-16363	Doran & Assoc., Inc.	J. Eckxtron No. 2 K-A-108	Carroll
41	31-013-15935	Doran & Assoc., Inc.	Waite Unit No. 1 KA-94	Carroll
42	31-013-16398	Doran & Assoc.s, Inc.	#1 Fatherstone KA-98	Carroll
43	31-013-17063	Doran & Assoc., Inc.	M. Anderson No. 1	Carroll

Table 1. Name, identification number, and location of drill holes correlated along transect B-B'. Map numbers identify the drill holes used in figures 3, 4, 5, and text. Location are shown in figure 3.

System	Series: European	Series: North American	Group	Sequence	Formation	Thickness (in feet)	Age	Lithologic description		Depositional summary
Silurian (part)	Ludlovian (part)	Upper (part)	Lockport	VI	Geulph Dol.	< 40 ?	late Ludlovian	Fine-grained oolitic dolomite, shaley in upper part. Contains sparse fossils and stromatolites.	hst	Progradational marine
					Eramosa Dol.	38-50	Ludlovian	Thick- to thin-bedded, bituminous, fossiliferous dolomite with chert horizons. Some units lack fossils.		
					Goat Island Dol.	26-56	earliest Ludlovian to latest Wenlockian	Lower Niagara Falls Mbr. is a biohermal grainstone; the middle Ancaster Mbr. is a thin-bedded, cherty, fossiliferous dolomite; upper Vinemount Mbr. is a thin- to medium bedded, fossiliferous, shaley, dolomite.		deeper marine (Vinemount Mbr.)
	Wenlockian	Lower			Gasport Dol.	20-37	latest Wenlockian	The Gothic Hill Mbr. is a fossiliferous dolograinstone to dolopackstone. The overlying Pekin Mbr. grades laterally from argillaceous dolomicrite to bioherms and dolorudites.	tst	shallow marine shelf
			Clinton: Upper	V	Decew Dol.	5-12	middle Wenlockian	Argillaceous to sandy dolomite with thin shale partings. Unit has sparse fossils and is characterized by contorted bedding.	hst	deep water offshore marine
					Rochester Sh.	2-120	early-middle Wenlockian	Lewiston Mbr. is a calcarious mudstone and is fossiliferous in its lower and upper parts. The overlying Burleigh Hill Mbr. is a calcarious to dolomitic mudstone; its upper part has abundant laminated pelletal grainstones and is increasingly calcarious upwards, grading to ls.		
					Irondequoit Ls.	12-22	earliest Wenlockian	Thick- to massive-bedded, fossiliferous, dolomitic, packstone and grainstone with medium to massive bedded, fossiliferous, limestone and thin shale interbeds in upper part.	tst	shallow water high energy
				IV	Rockway Dol.	7-12	earliest Wenlockian to late Telychian (C6)	Thin- to medium-bedded, burrowed, dolomitic wackestones with thin interbeds of dolomitic shale. Base contain Salmon Creek Phos. Bed comprised of bioturbated dolomicrite with quartz and phosphate pebbles.	hst	deep shelf
	Llandoverian				Williamson Sh.	< 1-79	late Telychian (C6)	Fissile shale containing graptolite fossils. Base contains Second Creek Bed comprised of quartz and phosphate pebbles.	tst	
			Clinton: Lower	II	Reynales Ls.	0-12	Llandoverian (C2)	Represented by Hickory Corners Member which consists of thin- to med.-bedded limestone with shale partings, fossils, and some chert.	tst	offshore carbonates and inner shelf muds
					Neahga Sh.	< 2-6	late Aeronian (B2-C1)	Fissel shale with sparse fossils. Basal Densmore Creek Phos. Bed contains nodules, pebbles, and cobbles of quartzite and phosphate in a sandstone matrix.		
			Medina	I	Kodak Ss.	< 1-11	Aeronian (B3)	Rhythmically interbedded sandstone and shale. Contains abundant trace fossils locally.	hst	tidal and shoreface
					Cambria Sh.	< 1-14	Aeronian (B3)	Interbedded fine grained ss., slst., and sh. with sparse fossils. Caliche horizons and desiccation cracks are in some western sections.		
					Thorold Ss.	5-10	Aeronian (B3)	Mottled, cross-bedded channel sandstone that grades laterally to a massive pelletal sandstone.		
					Grimsby Fm.	29-72	latest Rhuddanian to earliest Aeronian	Interbedded sandstone, siltstone, and shale. Basal 10-15 ft. is fossiliferous, bioturbated, and includes a phosphatic dolomite and pebble lag in the Artpark Phos. Bed. Overlying beds are f.-med. grained sandstone, conglomerate, and shale. Sandstone beds are planar laminated and hummocky cross-stratified in lower part and trough cross-stratified in upper part.		nearshore and offshore marine
					Devils Hole Ss.	13-15	Rhuddanian	Fine to medium grained, horizontally to hummocky cross laminated, well sorted sandstone with shale interbeds.	tst	
					Power Glen Sh.	11-28	Rhuddanian	Shale containing hummocky cross-stratified and bioturbated sandstone, dolomite, siltstone, limestone., and sparse fossils.		
					Whirlpool Ss.	18-28	early Llandoverian	Lower part is fine to medium grained sandstone, trough cross-stratified sandstone and contains large channel fills. The upper part is finner grained and hummocky cross-stratified sandstone.	smt	shoreface, fluvial in lower part
Ordovician					Queenston Sh.					offshore marine

Table 2 Stratigraphic nomenclature of Niagaran Provincial Series in Niagaran region. Stratigraphic nomenclature, ages, unconformities, lithologic descriptions and depositional interpretations are from Brett and others (1990, 1995). Sequence stratigraphic interpretations are from Brett and others (1990). Abbreviations: conglomerate (cgl.), sandstone (ss.), siltstone (slst.), shale (sh.), limestone (ls.), dolomite (dol), phosphate (phos.), formation (fm.), member (mbr.), fine (f.), medium (med.), coarse (c.), shelf margin systems tract (smt). transgressive systems tract (tst), highstand systems tract (hst). Unconformity (▪ ▪ ▪ ▪), minor unconformity (-------).

Preliminary correlations of the Medina, Clinton, and lower Lockport Groups along transect B-B' are shown in figure 4. Correlated formations are the Whirlpool Sandstone, Power Glen Shale, and Grimsby Formation of the Medina Group; the Reynales Limestone, Williamson Shale, Irondequoit Limestone, and Rochester Shale of the Clinton Group; and undivided strata of the Lockport Group. The Devils Hole Sandstone, Thorold Sandstone, Cambria Shale, Kodak Sandstone, Neahga Shale, and Rockway Dolomite are not recognized along the transect. The undivided Lockport Group contains strata that are coeval to the Gasport, Goat Island, Ermosa, and Guelph Dolomites.

Three laterally continuous depositional units are recognized in the siliciclastic strata that comprise the Medina Group along transect B-B' (fig. 5). The basal unit is 15-25 ft thick and consists of a fining-upward succession in the Whirlpool Sandstone and the lower part of the Power Glen Shale. The middle unit is 35-65 ft thick and consists of coarsening-upward successions in the upper part of the Power Glen Shale and lower part of the Grimsby Formation. The upper unit comprises the remaining 75 to 100 ft of the Medina Group and consists of laterally discontinuous units of sandstone, siltstone, and mudrock interbedded in coarsening- and fining-upward successions. In the Niagara region, these three units of the Medina Group are interpreted to contain shelf margin, transgressive, and highstand deposits within Sequence 1 (Brett and others, 1990)(table 2). However, stacking patterns observed in the Medina Group along transect B-B' suggest alternative sequence stratigraphic interpretations whereby the lower and middle units, respectively, comprise the transgressive and highstand systems tracts of Sequence I and the upper unit is within the transgressive systems tract of Sequence II (table 2). These interpretations are based on similarities of these rocks to sequence stratigraphic models described from Upper Cretaceous strata in southern Utah by Shanley and McCabe (1991) and Hettinger and others (1994).

The lower unit overlies the Cherokee unconformity (Brett and others, 1990) and fines upward from sandstone to siltstone and mudrock (fig. 5). Coeval rocks in the Niagaran Escarpment region demonstrate a significant basinward facies shift as well as a deepening upward facies succession through fluvial, shoreface, and offshore marine deposits. Fluvial deposits are placed in a shelf margin systems tract and the shoreface and offshore deposits are placed in a transgressive systems tract by Brett and others (1990). Similar interpretations are reasonable for strata within the lower unit of transect B-B'. However, all three facies may have been deposited within a transgressive systems tract during an overall retrogradational event whereby shallow incised valleys are backfilled with fluvial deposits during a rise in sea level. In both examples, overlying shoreface and

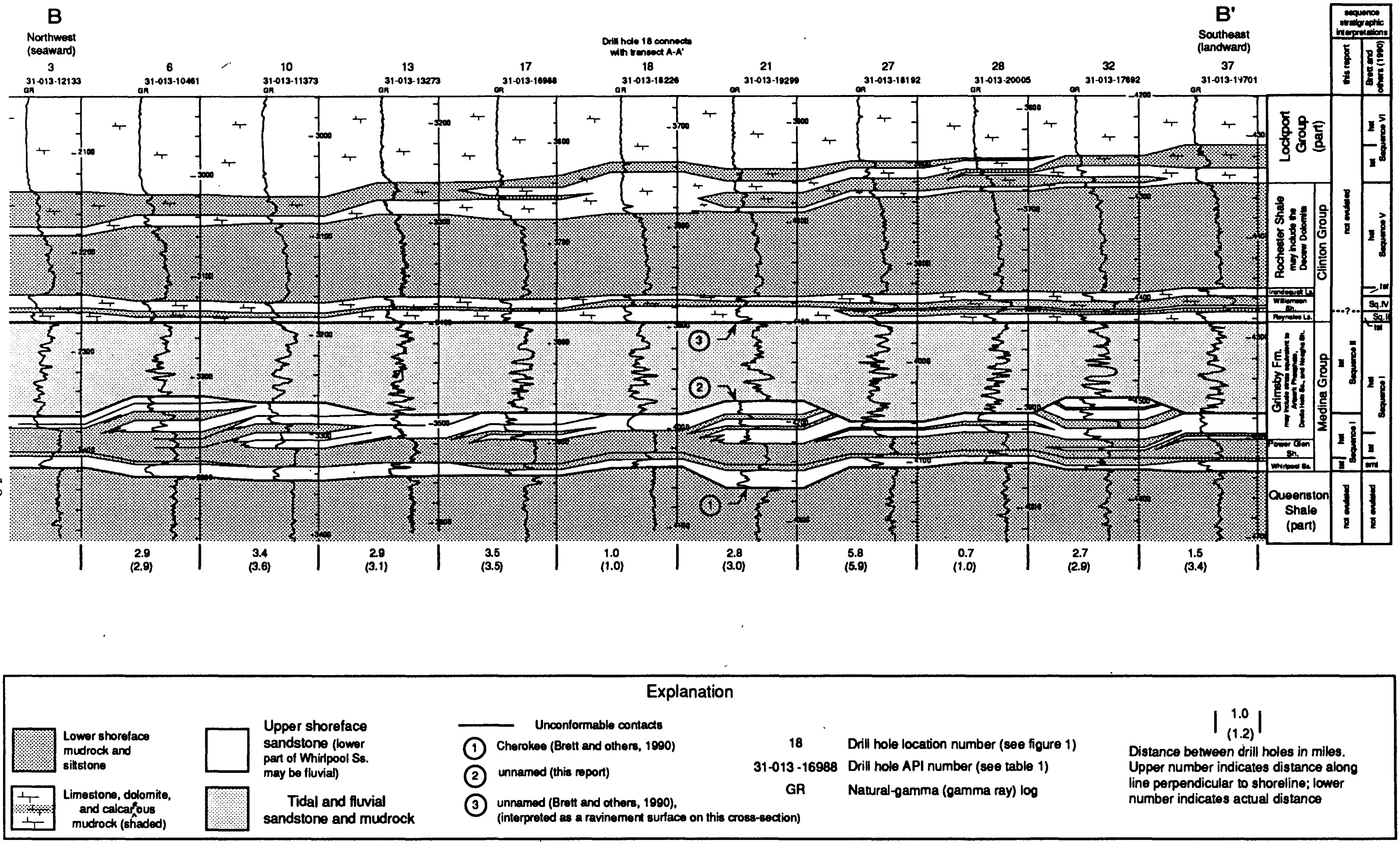

Figure 4. Preliminary stratigraphic interpretations of the Niagaran Provincial Series along transect B-B' in Chautauqua County, New York. Drill holes are located in figure 3 and identified in table 1. Sequence stratigraphic interpretations from this report are compared to those of Brett and others (1990) from the Niagara region of New York. Abbreviations are explained in table 2.

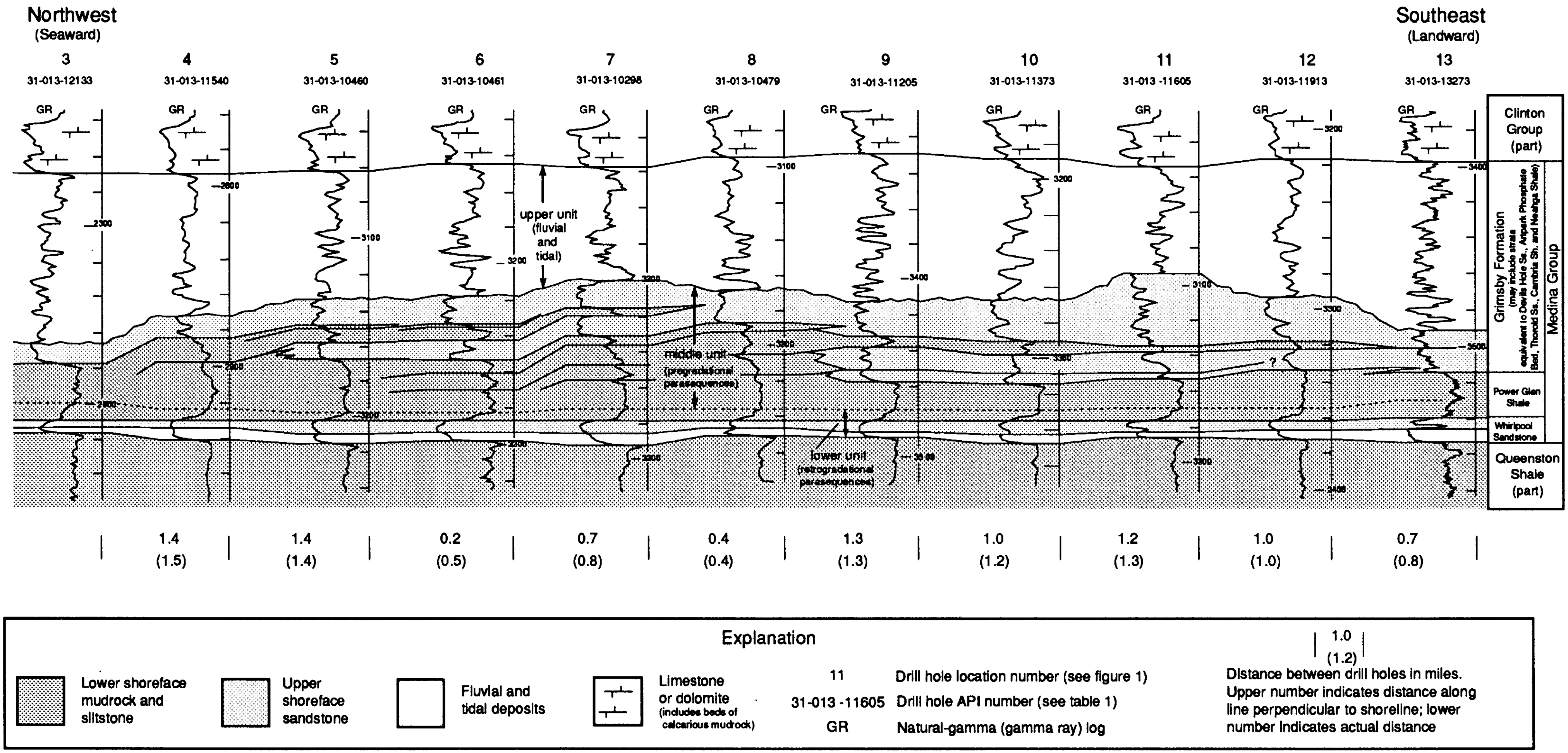

Figure 5. Shoreface stacking patterns in the Medina Group along transect B-B'. Progradational shoreface parasequences are interpreted from natural-gamma logs that show coarsening upward successions and laterally continuous sandstones that fine in a seaward direction. Retrogradational shoreface stacking patterns are interpreted in the lower part of the Medina Group from laterally continuous successions that fine upward from sandstone to siltstone and mudrock. Fluvial and tidal deposits are interpreted from serrated log signatures that show thin and fining or coarsening upwards stratal successions with limited latteral continuity. Shoreface, tidal, and fluvial interpretations are also based on sedimentological descriptions of coeval strata by Brett and others (1990, 1995) and Laughrey (1984). Lateral variations in the thickness of sandstones in the uppermost part of the progradational deposit suggest an unconformable contact with overlying fluvial and tidal rocks.

offshore marine strata were deposited during a marine transgression in response to a rise in sea level.

Coarsening-upward successions in the middle unit are 20-40 ft thick and pass upward through mudrock, siltstone, and sandstone. Sandstones are 10-20 ft thick and persist at least 10 mi in a northwest direction before they split, thin, and grade into siltstone and mudrock (fig. 5). Similar overlying successions forwardstep to the northwest and downlap onto the lower unit. These upward-coarsening and forward stepping characteristics suggest that the middle unit is a highstand deposit comprised of progradational shoreface parasequences. Interpretations of offshore and barrier bar deposits in coeval rocks in Pennsylvania (upper part of the Cabot Head Shale and lower part of the Grimsby Sandstone) by Laughrey (1984) support a shoreface interpretation. Correlations from the middle unit suggest that the upper part of the Power Glen Shale and Devils Hole Sandstone in the Niagara region are progradational rather than retrogradational as interpreted by Brett and others (1990). If this scenario is correct, the maximum flooding surface in the Niagara region may be a 2-ft-thick condensed interval at the top of the Whirlpool Sandstone (see Brett and others, 1990, fig. 4) rather than the base of the Artpark Phosphate Bed as interpreted by Brett and others, 1990).

The upper unit contains laterally discontinuous sandstone, siltstone, and mudrock interbedded in fining- and coarsening-upward successions. Siltstone and mudrock dominate the upper part of the unit. The basal contact is scoured into underlying shoreface strata and scours are as much as 35 ft deep and several miles across (see drill holes 21 through 32, fig. 4). The upper unit is interpretated to be fluvial and tidal in origin based on geophysical log signatures and core descriptions of the Grimsby Sandstone which contain braided river deposits in its middle part and tidal flat deposits in its upper part (Laughrey (1984). We interpret the basinward shift of braided river over nearshore strata to represent an unconformable facies relationship; this interpretation is further supported by the widespread erosional surface that separates the two facies along the transect. Strata in the upper unit is further interpreted to be within a transgressive systems tract based on its deposition over an erosion surface and retrogradational stacking patterns. Deepening-upward successions are characterized by braided river and superimposed tidal flat deposits in the Grimsby Sandstone (Laughrey, 1984), inner shelf muds of the Neahga Shale, and offshore carbonates of the Reynales Limestone (Brett and others, 1990). In this interpretation, broad valleys were cut into emergent highstand deposits of Sequence I and backfilled by fluvial strata during the initial stages of sea level rise that resulted in the deposition of Sequence II of Brett and others (1990). The fluvial deposits were subsequently covered by tidal deposits as the sea advanced. Continued rise in sea level resulted in marine transgression that cut a ravinement surface and deposited the pebble and cobble lag of the Densmore Creek Phosphate Bed followed by deposition of inner shelf muds and offshore carbonates. The top of the transgressive systems tract is interpreted to be eroded by the unconformity at the base of Sequence III following interpretations of Brett and others (1990).

Properly interpreted sequence boundaries, systems tracts, and depositional facies may be critical for understanding reservoir and production variability in the Clinton/Medina regional gas accumulation. For example, thick valleyfill sandstones of fluvial and(or) estuarine origin deposited in a transgressive systems tract may be an important control of production "sweet spots". This investigation of transect B-B' provides an alternative sequence stratigraphic interpretation for the Medina Group and lower part of the Clinton Group in New York State; however, core studies and additional detailed correlations are needed to substantiate the interpreted unconformity near the base of the Grimsby Formation and the tidal and fluvial origin of Grimsby Formation strata above the unconformity. Moreover, perforated gas-bearing zones and their initial and ultimate gas yield must be identified for each well of transect B-B' to determine which sequences, systems tracts, and depositional facies have the most favorable gas reservoirs.

Transect C-C'

A preliminary east-west cross section, several miles north of transect C-C', was prepared from seven drill holes used in deWitt and others (1975)(figs. 6, 7). This section shows the general stratigraphic relationships of the Lower Silurian Medina and Clinton Groups prior to studies by Piotrowski (1981), Laughrey (1984), and Zagorski (1991). For example, except for cross sections by Cate (1961) where a combined Irondequoit-Reynales lime was identified, the Irondequoit (Limestone) has only recently been recognized as a separate unit in northwestern Pennsylvania (Laughrey, 1984).

Twenty wells (table 3) along transect C-C' have been correlated with the Mark Resources Shaffer #1 well in the Cooperstown gas field (Zagorski, 1991)(fig. 7). Three of these wells are shown on figure 8: the Transamerica Acker #1 (API 37-039-20077), the Mark Resources Shaffer #1 (API 37-121-42719) and, to the east, the Quaker State Fee #1-H (API 37-053-21250). Only the Benedum Trees J. Kardosh #1 drill hole (P67; API 37-039-20007) is common to the two cross sections (fig. 6). The Reynales Limestone of the earlier preliminary cross section has been

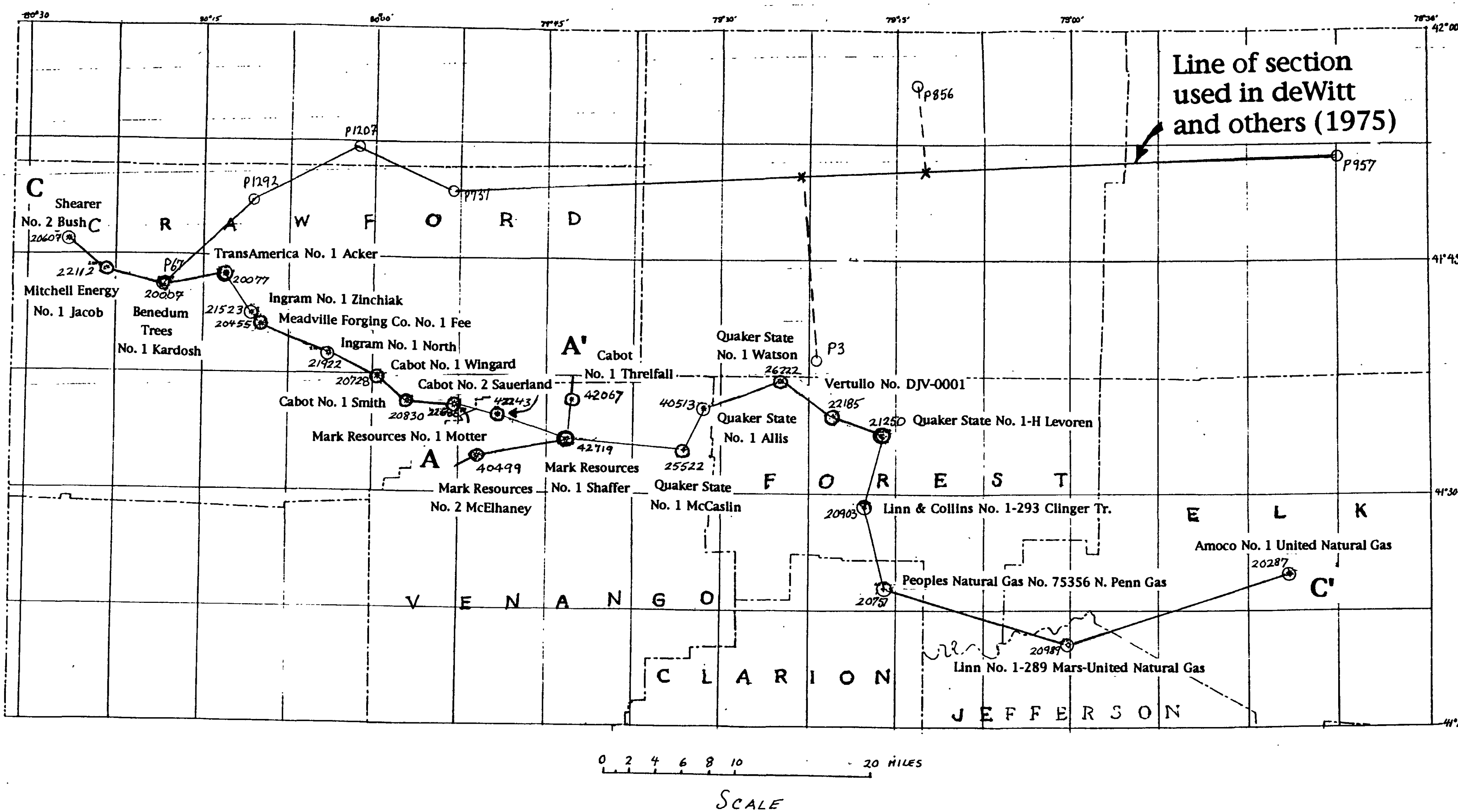

Figure 6. Map of six counties in northwestern Pennsylvania showing location and identification numbers of drill holes used in transect C-C' and in the east-west cross section in deWitt and others (1975). Identification numbers for the drill holes used in the northern cross section have been assigned by the Geological Sample Log Company, Pittsburgh, PA.

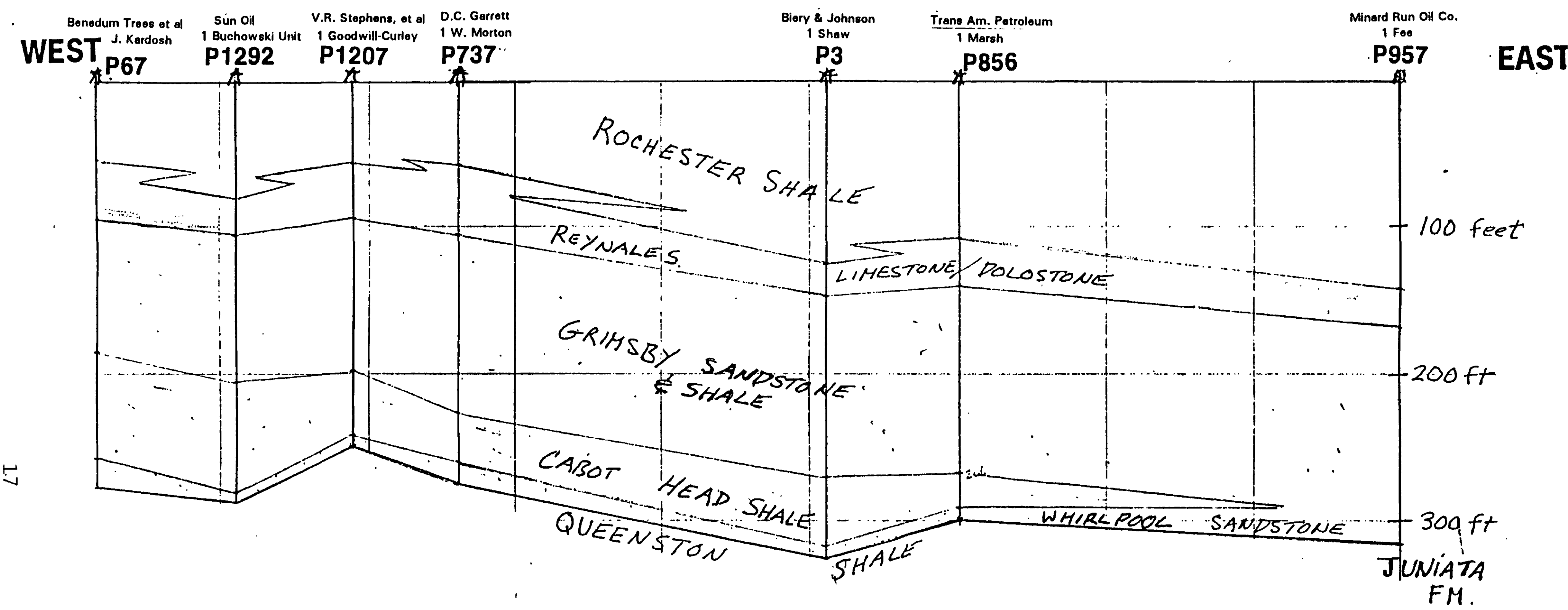

Figure 7. Preliminary east-west cross section through northwestern Pennsylvania based on drill holes used in deWitt and others (1975). Datum is the base of the Silurian Lockport Dolomite.

API UNIQUE #	County	Operator - Farm	Quadrangle (71/2')
37039-20607	Crawford	James I. Shearer - Bish #2	Beaver Center
37039-22112	Crawford	Mitchell Energy - Jacob #1	Linesville
37039-20007*	Crawford	Benedum Trees - Kardosh #1	Harmonsburg
37039-20077	Crawford	Transamerica - Acker #1	Meadville
37039-21523	Crawford	Ingram - Zinchiak #1	Meadville
37039-20455	Crawford	Meadville Forging Co - Fee #1	Meadville
37039-21922	Crawford	Ingram - North #1	Blooming Valley
37039-20728	Crawford	Cabot - Noah Wengard #1	Sugar Lake
37039-20830	Crawford	Cabot - ILA Smith #1	Sugar Lake
37039-22686	Crawford	Mark Resources - Motter #1	Sugar Lake
37121-42243	Venango	Cabot - Sauerland #2	Demseytown
37121-25522	Venango	Quaker State - McCaslin #1	Pleasantville
37121-40513	Venango	Quaker State - Allis #1	Pleasantville
37053-26222	Forest	Quaker State - Watson #1	West Hickory
37053-22185-D	Forest	Vertullo - #DJV-0001	Kellettville
37053-21250	Forest	Quaker Stata - Fee #1-H (Levoren [324] field)	Kellettville
37053-20903	Forest	E.H. Linn - E.S. Collins - ClingerTract #1-293	Tylersburg
37031-20751	Clarion	Peoples Nat. Gas - N. Penn Gas #75356	Tylersburg
37065-04071	Jefferson	E.H. Linn - Kittaning State Forest- UNG #1-289	Sigel
37047-20287	Elk	Amoco - United Natiural Gas #1-R	Ridgway

*P67 on figure 6

Table 3. Drill holes used in the preparation of transect C-C'.

reclassified into three carbonate units in transect C-C'. In ascending order, these carbonates are named, respectively, 1) the Irondequoit Limestone, 2) an unnamed limestone unit, and 3) the Reynales Limestone as restricted by Zagorski (1991). These latter correlations are shown in figure 8 and are used throughout the correlation of logs along transect C-C'. Care must be taken in the correlation of the carbonate intervals above the Medina Group sandstones. It would appear that the Dayton Limestone (Packer Shell) has been confused with the Reynales Limestone in western Pennsylvania.

Commonly, the bulk density of the basal part of the Reynales Limestone in the western part of transect C-C' is high with respect to the bulk densities of the younger carbonates. The most likely explanation is that the basal unit of the Reynales Limestone is dolomite rather than limestone.

A preliminary examination of bulk density values within the sandstone intervals of the Whirlpool Sandstone, Cabot Head Shale, and the Grimsby Formation along transect C-C' indicates that the Whirlpool Sandstone commonly has very low porosity. Porosity values calculated for sandstones in the Cabot Head Shale and the Grimsby Formation commonly range from 3-4%. These porosity values calculated from well logs, however, are considerably lower than the 5-8% porosity values measured from core in nearby wells (Laughrey, 1984).

Transect D-D'

Lack of funds for geophysical logs in Ohio prevented the completion of transect D-D' in FY1995. This transect should be completed in FY1996.

Transect A-A'

During FY95 geophysical logs from about 100 drill holes were correlated across transect A-A', thus, providing us with a reasonably good understanding of the distribution of Lower and lower Upper Silurian strata across the length of Clinton/Medina gas play 6728. The transect is incomplete across several 10- to 20-mi-wide gaps where well logs have not been purchased. For this report, seven drill holes were selected to characterize the preliminary stratigraphic correlations and framework along transect A-A' (figs. 9, 10). Stratigraphic nomenclature for the Medina and Clinton Groups in New York follows Brett and others (1995). In most cases, the New York terminology for the Medina and Clinton

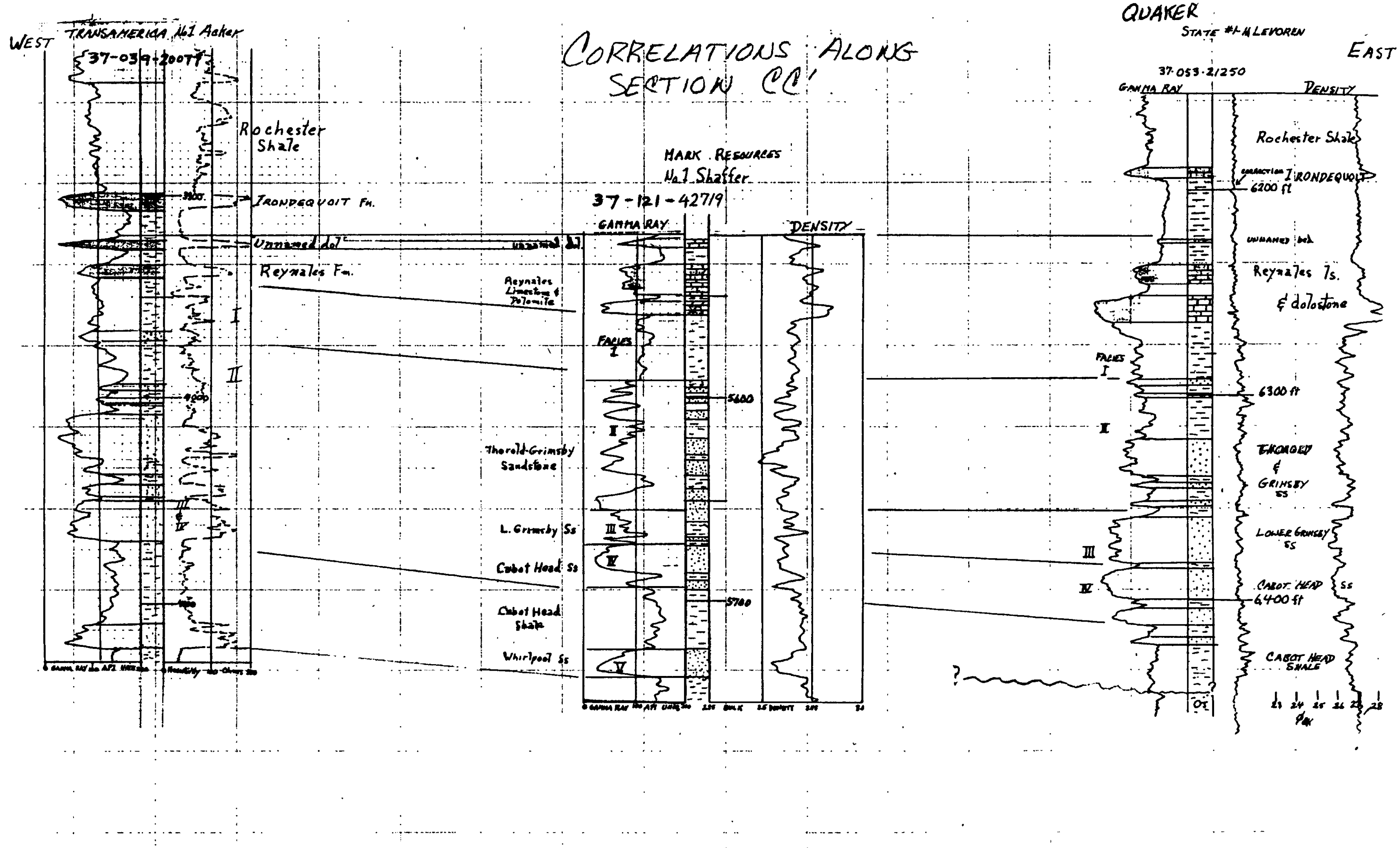

Figure 8. Correlation of Medina Group sandstones and overlying Clinton Group carbonates and shale between three drill holes along transect C-C'. See figure 6 for location of the drill holes.

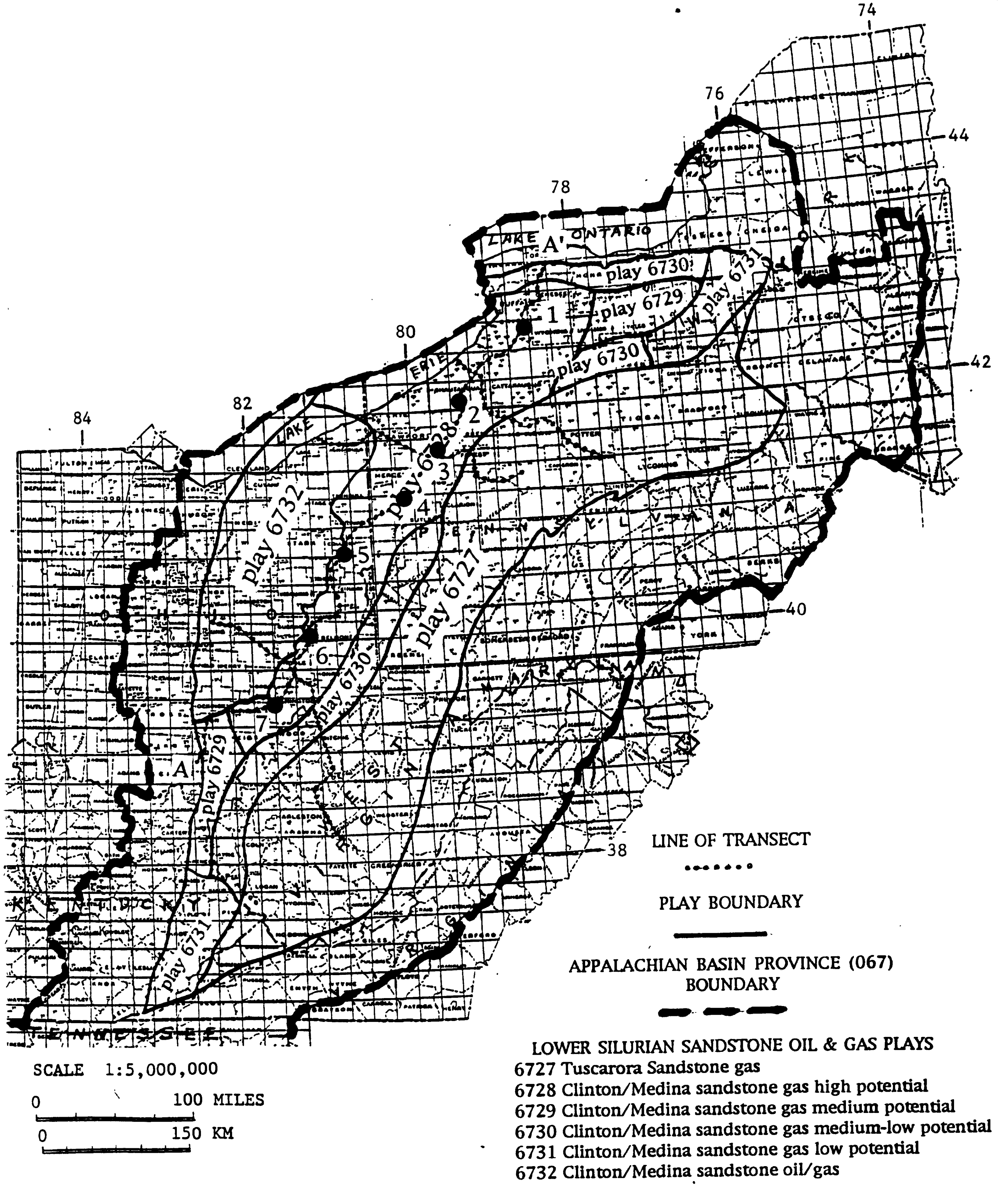

Figure 9. Map of the northern part of the Appalachian basin province (067) showing oil and gas plays in Lower Silurian sandstones and location of drill holes (in figure 10) along transect A-A'.

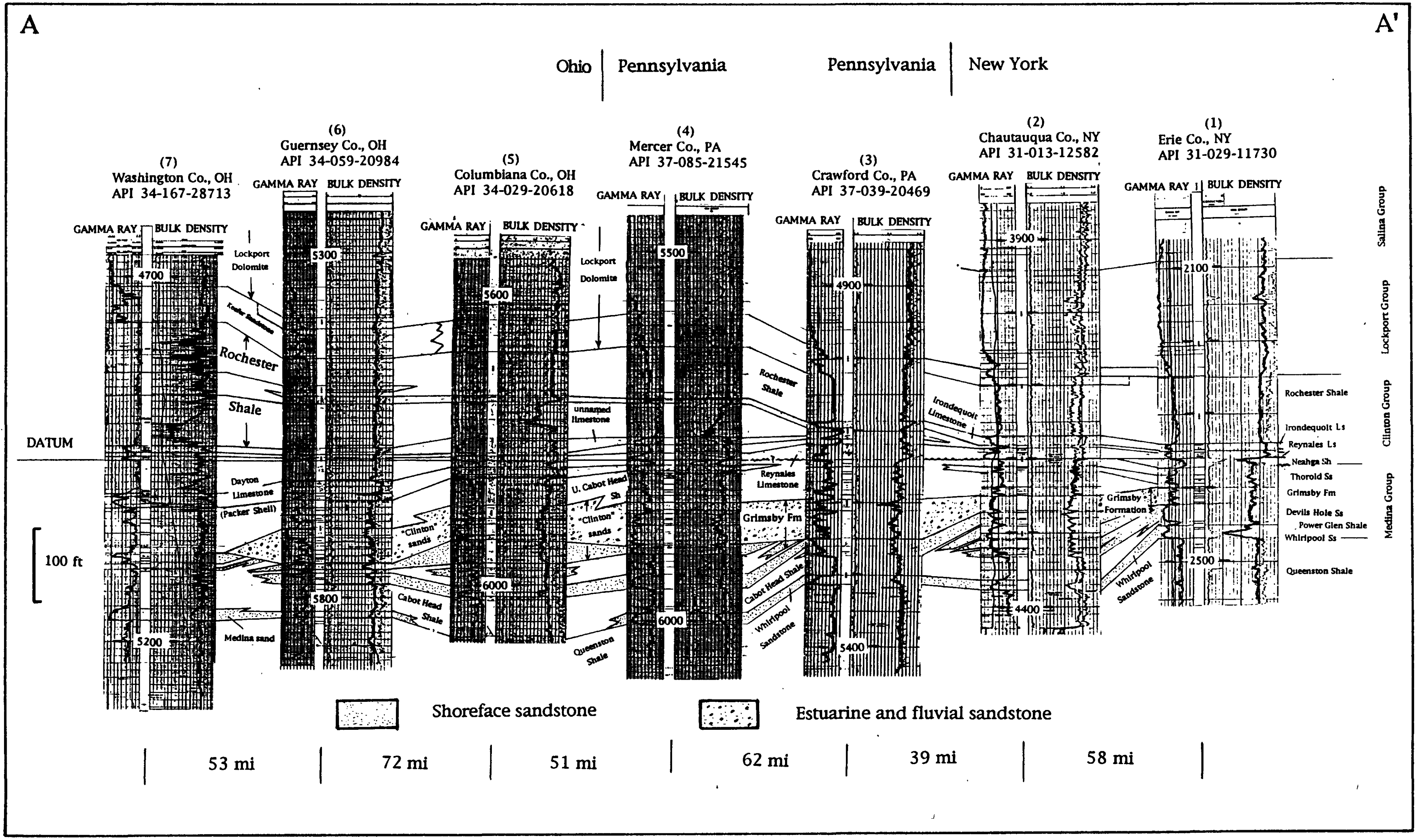

Figure 10. Correlation of "Clinton" sands, Medina Group sandstones, Clinton Group, and Lockport Group between selected drill holes along transect A-A'. See figure 9 for location of drill holes.

Groups can be extended into Pennsylvania (Piotrowski, 1981; Pees, 1983; Laughrey, 1984). In Ohio, a combination of commonly used driller's terms and formal nomenclature are applied to strata equivalent to the Medina and Clinton Groups (Pepper and others, 1953; DeBrosse and Vohwinkle, 1974; Gray and others, 1985).

One important aspect of the transect is that it shows regional thickness variations of the Medina Group in New York and Pennsylvania and of equivalent strata (Medina sand, Cabot Head Shale, "Clinton" sands, upper tongue of the Cabot Head Shale) in Ohio (fig. 10). The maximum thickness of the Medina Group and equivalent strata along transect A-A' is located in the vicinity of Mercer County, PA (drill hole 4) and Columbiana County, OH (drill hole 5)(figs. 9, 10). The 210- to 220-ft-thick Medina Group and equivalent strata there constitute part of the Canton embayment, a depocenter recognized by Knight (1969) consisting of Medina Group siliciclastic units, lowermost Clinton Group carbonate units, and equivalent strata. From this depocenter, the Medina Group thins northward to about 96 ft in Erie County, NY (drill hole 1) and southward to about 156 ft in Washington County, OH (drill hole 7) (figs. 9, 10).

A second important aspect of the transect is that it shows the net thickness and geometry of sandstone in the Medina Group, "Clinton" sands, and Medina sand. Net sandstone thicknesses in the Medina Group and equivalent strata in the seven selected drill holes are greatest in Mercer County, PA (drill hole 4, 96 ft), Chautauqua County, NY (drill hole 2, 90 ft), and Columbiana County, OH (drill hole 5, 85 ft)(figs. 9, 10). The Chautauqua County, NY site, located nearly 100 mi north of the Canton embayment, represents a subsidiary sandstone depocenter in the "Clinton" sand and Medina Group sequence. The net sandstone thickness of the Medina Group interval thins to 64 ft in Erie County, NY (drill hole 1) at the north end of the transect and to 29 ft in Washington County, OH (drill hole 7) at the south end (figs. 9, 10).

Basal sandstone units in the Medina Group and equivalent units (Whirlpool Sandstone and Medina sand) are characterized by an 8- to 20-ft-thick, well-defined low ("clean") gamma ray log response that gradually changes upward to a higher response (higher clay content)(fig. 10). This log shape has been interpreted by Metzger (1981) and Laughrey (1984) to represent sublittoral sheet sandstones. Based on outcrop studies, Middleton and others (1987) suggest that the lower part of the Whirlpool Sandstone has been deposited in a braided fluvial environment. Sandstone units in the Devils Hole Sandstone, upper part of the Cabot Head (Power Glen) Shale, lower part of the Grimsby Formation, and lower part of the "Clinton" sands are 10 to 30 ft thick and commonly have blocky to upward-decreasing ("cleaner") gamma ray log responses (fig. 10). These log shapes have been interpreted in previous investigations to represent littoral (barrier bars and tidal deltas), distributary mouth bar, distributary channel, tidal-dominated delta, tidal ridge, and offshore marine bar sandstones (Metzger, 1981; Laughrey, 1984; Keltch, 1985). Directly overlying these shallow-marine sandstones are 2- to 14-ft- thick sandstone units in the upper part of the Grimsby Formation and "Clinton" sands that have spike-shaped to upward-increasing (higher clay content) gamma ray log responses (fig. 10). These log shapes have been interpreted in earlier investigations to represent braided fluvial channel, meander point bar, and tidal channel sandstones (Metzger, 1981; Laughrey, 1984; Keltch, 1985).

In this report, the Whirlpool Sandstone and Medina sand are interpreted as shoreface or sublittoral sheet sandstones, possibly with a lowermost braided fluvial component, deposited in a transgressive systems tract that unconformably overlies the Upper Ordovician Queenston Shale. This unconformity is recognized as the Cherokee unconformity by Brett and others (1990). Following the preliminary interpretation of the middle unit in transect B-B' (fig. 5), sandstones in the lower part of the Grimsby Formation and "Clinton" sands with blocky and upward-decreasing gamma ray responses are identified here as shoreface sandstones deposited in a highstand systems tract (fig. 10). These shoreface sandstones constitute parts of progradational parasequences that successively overlap one another toward the northwest, pinch out seaward into offshore marine shale of the Cabot Head and Power Glen Shales, and appear to downlap across the underlying transgressive systems tract. Although transect A-A' is largely oriented normal to depositional strike, it has a slight dip-oriented component that cuts obliquely across the paleoshoreline from north to south in a seaward direction and exhibits locally the stacking and westward progradational character of the parasequences (Figs. 9, 10). The Devils Hole Sandstone of Brett and others (1990, 1995) and informally named sandstones in the Cabot Head Shale (Pees, 1983; Laughrey, 1984; Zagorski, 1991) are interpreted here to be part of the same progradationally stacked parasequences. Following the interpretation of the upper unit in transect B-B' (fig. 5), sandstones with spike-shaped and upward-increasing gamma ray responses that overlie the shoreface sandstones are identified here as estuarine (tidal) and fluvial sandstones in a transgressive systems tract deposited unconformably across a highstand systems tract (fig. 10). The unconformable contact between the proposed highstand and transgressive systems tracts is subjective because of the variety of gamma ray log signatures involved. This boundary may mark a previously unrecognized sequence boundary (unconformity) caused by a eustatic fall in sea-level (see discussion of transect B-B').

A third important aspect of transect A-A' is that it shows the regional distribution of carbonate units in the Clinton Group (Reynales

Limestone, Irondequoit Limestone, Dayton Limestone, Packer Shell of drillers). These units are commonly used as a datum horizon for stratigraphic cross sections (transects) through the "Clinton" sands and Medina Group sandstones or the contoured horizon on structural contour maps. Figure 10 shows that, although these carbonate units are regionally extensive, long-distance correlations between them can be erroneous because of pinch outs and thickness changes in the intervening shale beds. The Irondequoit and Reynales Limestones extend across most of transect A-A' and the latter unit is used as the datum horizon (fig. 10). However, at the north end of the transect in New York State they are separated from one another by 2 to 5 ft of shale whereas at the south end in Ohio they are separated by a 70-ft-thick shale and a 10-ft-thick unnamed limestone unit. This unnamed limestone extends as far north as Crawford County, PA. The Dayton Limestone (Packer Shell of drillers) is located stratigraphically about 45 ft beneath the Reynales Limestone in southern Ohio (drill hole 7, Washington County, OH) and extends as far north as northwestern Pennsylvania (drill hole 4, Mercer County, PA) where it underlies the Reynales Limestone by less than 10 ft (figs. 9, 10).

GAS PRODUCTION AND DECLINE OF SELECTED WELLS

Estimated ultimate recoverable (EUR) gas from individual wells is an essential parameter for assessing recoverable gas in continuous-type (unconventional) accumulations in reservoirs such as the "Clinton" sands and Medina Group sandstones (Schmoker, 1995b). Basically, the EUR probability distribution for a set of producing wells in a given play can be used to approximate an expected EUR distribution for wells in undrilled parts of the play. EUR's either may be calculated directly from production-history records of abandoned wells or calculated from production decline curves of active or shut-in wells. As a rule, wells must have produced gas from the same reservoir for at least 5 years to provide a reliable decline curve. In the Appalachian basin, oil and gas production data for fields and wells have been compiled by most State Oil and Gas Agencies and State Geological Surveys since the early 1960's and many of them are available in digital form. Proprietary production files and data bases have been compiled by several oil and gas companies and consulting geologists in the basin. Several of these proprietary files may be purchased in digital form. Large commercial organizations such as Petroleum Information Corporation (PI) and Dwights Data Corporation have compiled very few oil and gas production records for the Appalachian basin.

In May 1994, the Ohio Division of Geological Survey provided the USGS with an 11,000 well digital production file to assess Clinton/Medina sandstone gas plays for the 1995 National Assessment of oil and gas. Production data from 1972 through 1986, organized by county, township, formation, well, and field, are recorded in this data file. Since then, the Ohio Survey has increased their oil and gas production file to about 37,000 wells. A major activity for FY95 was to identify and acquire well production data in the States of New York and Pennsylvania and to acquire the update of the production data base in Ohio.

Approximately 37,000 annual production records from 10,000 wells in 6 counties in western New York State were acquired from the New York State Department of Environmental Conservation (Bureau of Oil and Gas Regulation, Division of Mineral Resources) in early 1995. The records extend from 1985 through 1994 and are organized by county, township, formation, field, and well. Production data as far back as the early 1960's are stored on paper records but have not yet been converted to digital form. An additional 6,000 well records were acquired in the 6 counties of western New York for which no production records are available. Also in early 1995, deep reservoir production data consisting of 32,000 wells in 5 counties in northwestern Pennsylvania was acquired from the Pennsylvania Topographic and Geologic Survey. These data record oil and(or) gas production from units below the Middle Devonian Tully Limestone and are organized by County, 7.5 minute quadrangle, formation, field, and well. Because of a five-year confidentiality clause, the data file is restricted to annual gas production from 1980 through 1989. Annual updates will be made available for New York and Pennsylvania production records through the respective State agencies. The 26,000 well, production-records update in Ohio is still being compiled and edited by the Ohio Division of the Geological Survey and should be available to interested users in early 1997.

The New York, Ohio, and Pennsylvania production files are presently stored in the USGS Wells database. To date, an evaluation of these production records has been limited to selected wells in eastern Ohio where EUR's were calculated for the 1995 National Assessment. Decline curve analysis is planned for wells along or nearby the transects so that their gas yields can be compared with stratigraphic and structural characteristics of the "Clinton" sands and Medina Group sandstones.

DATA STORAGE AND DIGITAL MAPS

Land use-land cover and political-boundary data from the EROS Data Center in Sioux Falls, South Dakota were converted into ARC/INFO coverage for this project. When combined with existing play boundary maps and oil and gas cell maps from the 1995 National Assessment (Ryder,1995; Beeman, 1995), also in ARC/INFO format, they illustrate the types of environments that are impacted by Clinton/Medina sandstone gas plays. PI's Well History Control System (WHCS) file, consisting of over 100,000 wells for the Appalachian basin, was used by Beeman (1995) to create the oil and gas cell maps. Figure 11 shows a representative piece of the resulting map for northeastern Ohio and adjoining Pennsylvania.

Land use and land cover on figure 11 is differentiated with colors coded by general type (see explanation for fig. 11). Each 1/4-mile-square area(cell) of figure 11 that was drilled into or through the Clinton/Medina interval is shown by an X. The X's are color-coded according to the production status of the drill holes (see explanation for fig. 11). For example, a red X indicates that at least one gas well produces from the Clinton/Medina play in the cell.

Also for this project, an oil and gas field map was compiled for "Clinton" sands, the Medina sand, Medina Group sandstones, and the Tuscarora Sandstone at a scale of 1:500,000. States that are shown on the map and have production from the Clinton/Medina/Tuscarora interval are Kentucky, New York, Ohio, Pennsylvania, and West Virginia. An example of this oil and gas map from a three-county area of southeastern Ohio is shown in figure 12. This map probably will be digitized into ARC/INFO format in FY1996.

Analyses of formation water produced from the "Clinton" sands, Medina sand, Medina Group sandstones, and the Tuscarora Sandstone are available in a brines data file compiled for a joint USGS/Department of Energy/University of Oklahoma project in the 1970's. The file contains approximately 6,000 analyses for the Appalachian basin. An additional 100 brine analyses, with interpretations, were acquired from the New York State Department of Environmental Conservation (Bureau of Oil and Gas Regulation, Division of Mineral Resources). These formation water analyses are stored in a USGS database for future studies of water quality and water volume in gas-bearing Clinton/Medina/Tuscarora sandstone reservoirs.

Explanation for Figure 11

Land Use/Land Cover

pink	Land used for urban, commercial, industrial, and transportation activities
white	Agricultural land
green	Forest land
dark blue	Wetlands
light blue	Lakes, rivers, and reservoirs
gray	Barren lands that include quarries and strip mines

Hydrocarbon Production Status

Each X represents a 1/4-mi-square area (cell)
that was drilled into or through the Clinton/Medina interval

X green	Oil
X red	Gas
X purple	Oil and Gas
X black	Nonproductive

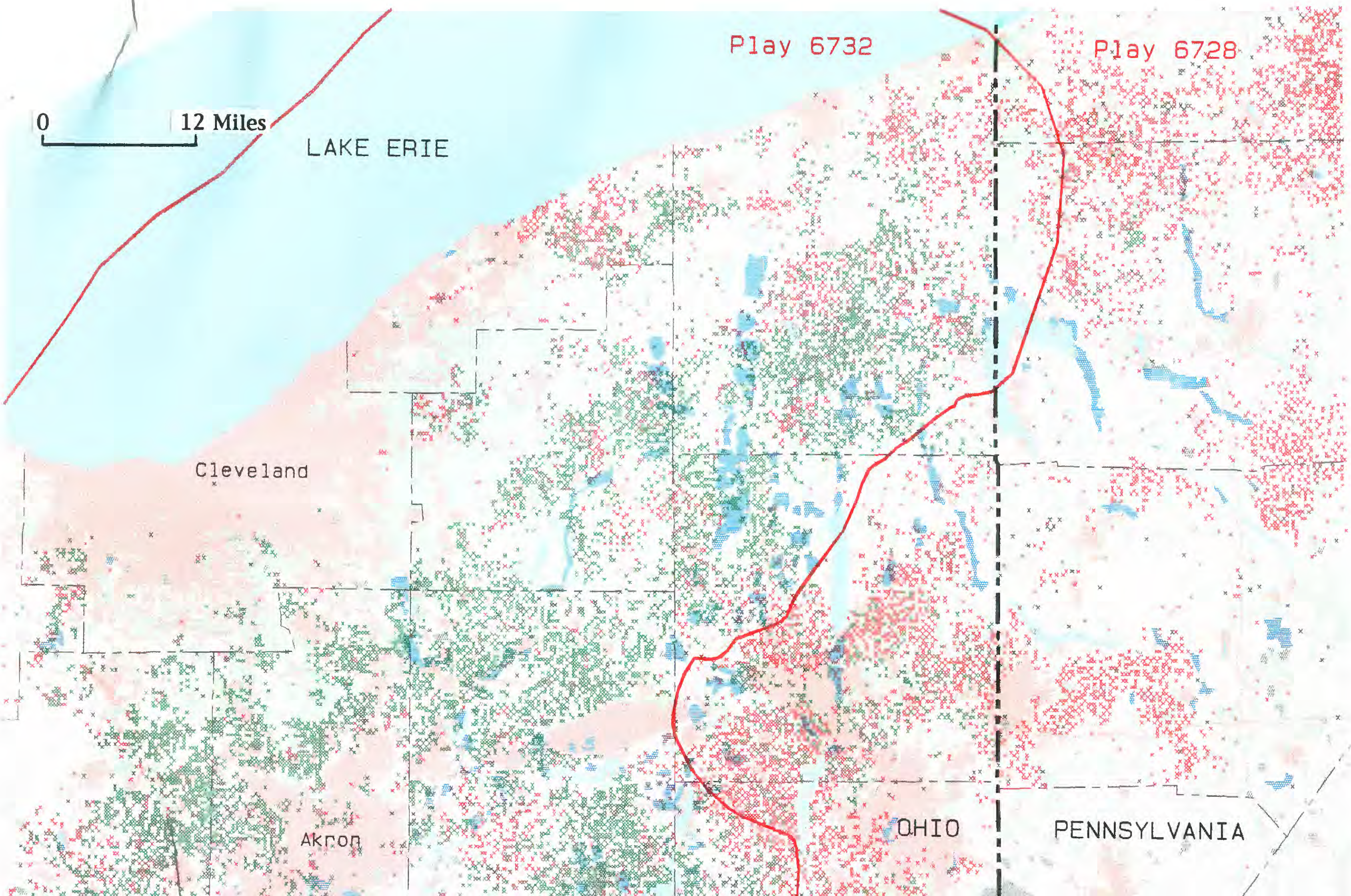

Figure 11. Map of Northeast Ohio and Northwest Pennsylvania showing land use/land cover and hydrocarbon production status by 1/4 sq mi cells for wells penatrating the "Clinton" sand and Medina Group sandstones.

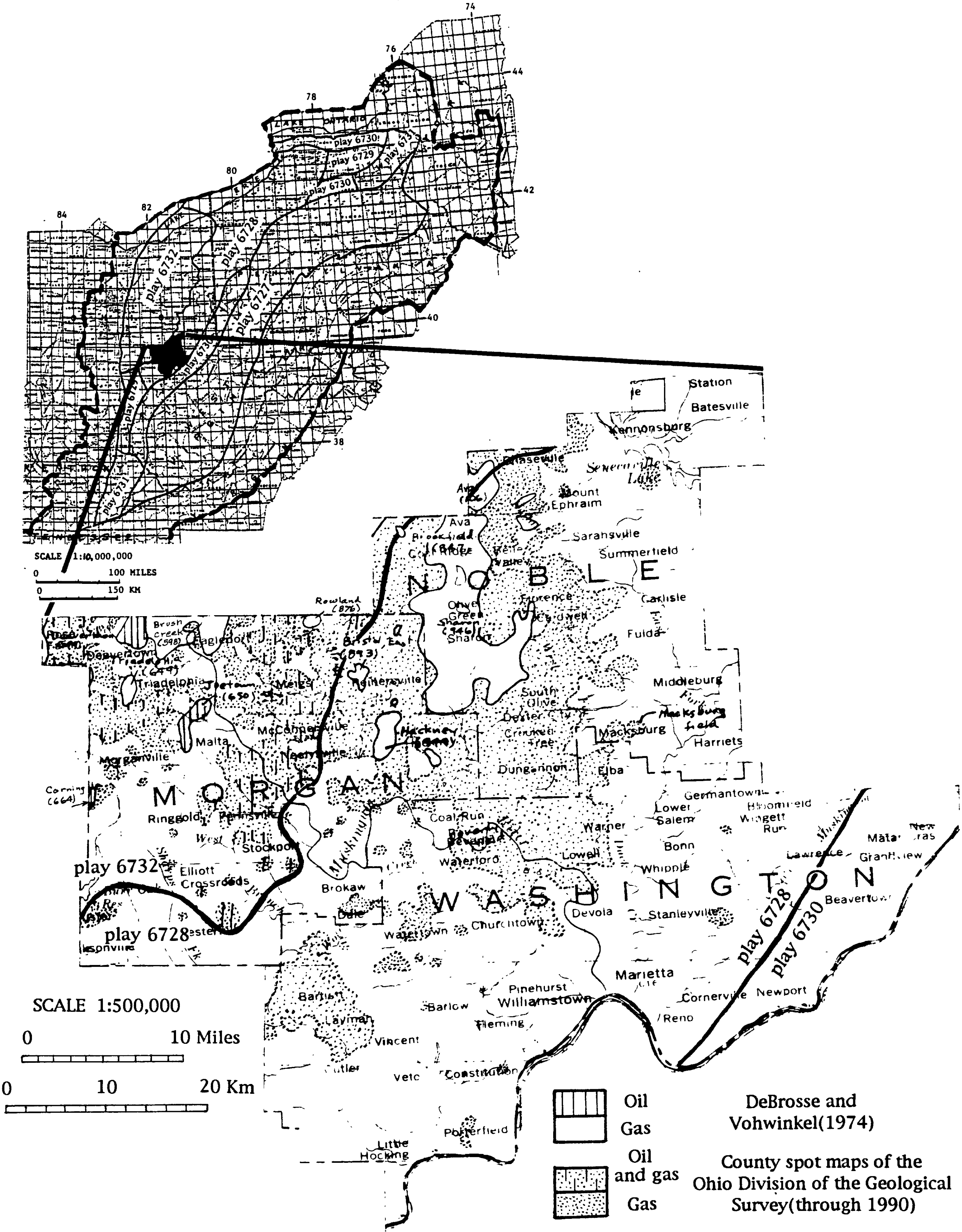

Figure 12. Map(part) of oil and gas fields that produce from the "Clinton" sands, Medina Group sandstones, and Tuscarora Sandstone. Sample from Morgan, Noble, and Washington Counties, Ohio.

STRUCTURE-CONTOUR AND DRILLING-DEPTH MAPS

Because of the large number of wells in the Clinton/Medina/Tuscarora play, the initial problem to be addressed is to determine the feasibility of constructing structure-contour and drilling-depth maps by machine from existing databases. Approximately 78,000 of the 211,000 wells in PI WHCS data files for the Appalachian basin penetrate the Clinton/Medina/Tuscarora interval. Although the regional structure of the producing interval is characterized by gentle, eastward homoclinal dip, with low and fairly uniform structural relief, enhanced gas production has been attributed to local structures by some workers (for example, Osten, 1982; Zagorski, 1991). These structures may include anticlines, anticlinal noses, terraces, and fault zones, all of which may influence hydrocarbon entrapment and(or) fracturing in Clinton/Medina/Tuscarora sandstone reservoirs. In order to identify such features it will be necessary to utilize as many data points as possible, preferably with various contouring packages and the WHCS database. Use of the WHCS database is, however, complicated by the use of inconsistent operator terminology to identify stratal units.

A test map showing structural contours has been constructed for the study area at a scale of 1:500,000 using the Dynamic Graphics Inc. Interactive Surface Modeling (ISM) system and WHCS data files. The top of the Packer Shell or the Reynales Limestone (fig. 10) was chosen as the datum because they are well represented in the database and assumed to be approximately equivalent. The north-central Ohio portion of the map is shown at a reduced scale in figure 13. The entire map utilizes approximately 58,000 data points and covers most of the play areas. Regional structure is adequately shown on the map, but there are a number of artifacts that may be a function of data distribution or miscorrelation. The Packer Shell and Reynales Limestone are convenient datum horizons from a geological standpoint, in that they are widespread, easily picked on geophysical logs, and probably reasonably approximate time lines. Subsequent correlations (fig. 10) show that, in fact, the Packer Shell and Reynales Limestone are not equivalent. In southern Ohio, for example, the Dayton Limestone (Packer Shell) (fig. 10) is typically more than 30 ft below the Reynales Limestone. Furthermore, there are a number of differences as to the usage of the terms Packer Shell and Reynales within the WHCS database and these differences affect the structure contours to some degree. In New York and Pennsylvania, for example, the Irondequoit Limestone (fig. 10) is commonly identified as Packer Shell in the WHCS database and, where identified as such, ranges

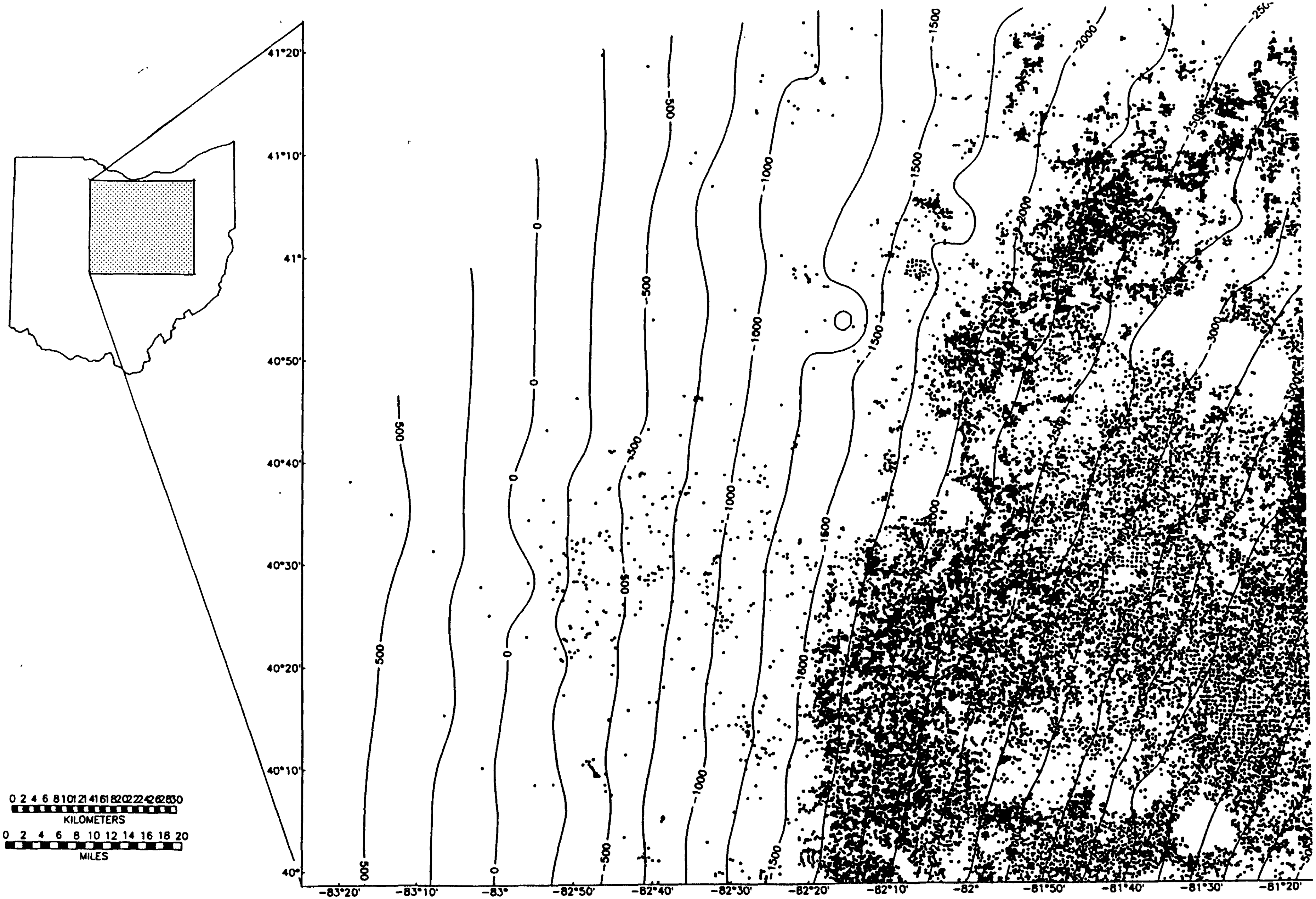

Figure 13. Structure-contour map drawn on the top of the Packer Shell/Reynales limestone interval in north-central Ohio. Contours were drawn using the Interactive Surface Modeling (ISM) System and Petroleum Information Corporation WHCS data files. The contour interval is 250 ft.

from about 15 ft higher than the Reynales Limestone datum in New York to over 30 ft higher in Pennsylvania.

Such discrepancies may be tolerable on a regional level, particularly, at the original map scale of 1:500,000 and at the contour interval of 250 ft shown in figure 13. However, because the Packer Shell has been inconsistently picked in the WHCS database, it is possible that use of this datum, without editing, would be unsatisfactory at larger scales. Also, "Clinton" sands and sandstones of the Medina Group are inconsistently picked in the WHCS database. The database is now being examined for other possible datums. This work is still in progress, but initial indications are that other structural datums may be more suitable for searching the WHCS database, such as, the top of the Medina Group in New York and Pennsylvania and the top of the "Clinton" sands in Ohio.

In addition to preliminary work with the WHCS database, a fairly comprehensive search of the literature on structure below the Upper Silurian Salina Group salt in the play area has been made. Most of the literature is in the form of graduate-school theses. Twenty six such theses were obtained through inter-library loans and were searched for structural information, as well as other information pertinent to the project. Other sources of existing sub-salt structural information are mostly limited to State geological survey reports that are typically generalized or cover only small areas. The literature search has identified several articles where cross-strike discontinuites (CSD's) of Wheeler, (1980) may have influenced hydrocarbon production (Rodgers and Anderson, 1984; Coogan, 1991). These CSD's will be incorporated into the structure and depth maps subject to time limitations and software capabilities.

RESERVOIR PRESSURE AND TEMPERATURE

One of the more important defining characteristics of continuous-type (basin-centered) gas accumulations is their pressure history. Continuous-type (basin-centered) gas accumulations are always abnormally pressured. They are either overpressured or underpressured with respect to normal hydrostatic pressure gradients which range from 0.43 to 0.46 pounds per square inch per ft (psi/ft), depending on the salinity of the formation water. In the Appalachian basin, Russell (1972) first recognized abnormally low reservoir pressures in the "Clinton" sands. Later, Davis (1984), Zagorski (1988; 1991), and Law and Spencer (1993) suggested that the abnormally low pressures in "Clinton" sands and Medina Group sandstone reservoirs were indicative of a regional, continuous-type (basin-centered) accumulation. Law and Dickinson (1985) suggested that the abnormally low pressures in low-permeability reservoirs, like those in "Clinton" sands and Medina Group sandstone reservoirs, had evolved from an earlier abnormally high pressure history caused by hydrocarbon generation.

Based on analogs of continuous-type (basin-centered) gas accumulations in the Rocky Mountain region, we have developed a working hypothesis that the Clinton/Medina sandstones and the equivalent Tuscarora Sandstone in the Appalachian basin should have three pressure domains; a normally pressured domain, a low-pressured domain, and a high-pressured domain. The normal and underpressured domains have been fairly well defined by industry operators in the region. The normally pressured domain is located in east-central Ohio (Davis, 1984, Thomas, 1993) where "Clinton" sands produce oil and gas with water. This normally pressured domain coincides approximately with Clinton/Medina sandstone oil/gas play 6732. In eastern Ohio and western Pennsylvania and New York, downdip from the normally pressured "Clinton" sands, is the underpressured domain. Since the inception of this project, abnormally low pressures have been verified throughout most of northwestern Pennsylvania and adjoining western New York (play 6728). Pressure gradients measured here commonly range from 0.30 to 0.40 psi/ft. The location of the transition into updip, normally pressured reservoirs is uncertain, however, and remains an objective of this project.

The postulated overpressured domain, may be located east of the underpressured domain, where the "Clinton" sands, Medina Group sandstones, and the equivalent Tuscarora Sandstone are more deeply buried and present-day subsurface temperatures are higher than at shallower depths. Empirical evidence in the Rocky Mountain region has shown that in rock sequences that have adequate amounts of organic carbon to generate hydrocarbons (a condition not yet confirmed for Lower Silurian strata in the Appalachian basin), the top of the zone of active generation of hydrocarbons and overpressuring occurs at temperatures of about 200°F (90°C). In areas where the rocks have experienced a cooling event, a common situation in most basins, the top of overpressuring may be significantly less than 200°F(90°C). Our search for this overpressured component has just begun; however, there are some encouraging beginnings.

A report by Avary (in press) indicates that some of the Lower Silurian Tuscarora Sandstone reservoirs in the Runville, Black Moshannon, and Devils Elbow gas fields near the Allegheny structural front in Pennsylvania are overpressured (0.5 - 0.6 psi/ft). The depth to the Tuscarora Sandstone in these fields ranges from 8,100 - 11,100 ft and reservoir temperatures range from 138 - 167°F. However, because these gas fields produce from anticlinal traps there is some uncertainty about the pressure relationships. For example, high reservoir pressures (greater than hydrostatic pressures) are common in hydrocarbon accumulations that have long columns. Thus, the reservoir pressure in these fields may, in fact, be normal when considering their mode of accumulation. Through the next year, one of our objectives will be to determine the pressure conditions of the Tuscarora Sandstone. The recognition of a regionally overpressured domain in the Tuscarora Sandstone would have the effect of enlarging the geographic and stratigraphic distribution of the Clinton/Medina continuous-type (basin-centered) gas accumulation in the Appalachian basin.

DOWNDIP LIMIT OF WATER PRODUCTION

Another diagnostic characteristic of continuous-type (basin-centered, deep basin) gas accumulations is the absence or near absence of producible formation water (Masters, 1979; 1984). Masters (1979; 1984) further reports that water-deficient, gas-saturated sandstone reservoirs in continuous-type gas accumulations are replaced updip by water-saturated sandstones that control entrapment. These zones of predominantly gas-saturated/little producible water and gas-bearing/water-saturated sandstones, as well as an intervening transition zone, can be interpreted from resistivity logs (Masters, 1979; 1984). Analogous zones of low-water, gas-saturated zones flanked by updip high-water saturated oil-and gas-bearing zones are noted by Davis (1984) and Zagorski (1991) in the Appalachian basin. Based on 33 control points, Davis (1984) suggests that the change from gas-saturated "Clinton" sands with little producible water to gas-bearing "Clinton" sands with high water saturation occurs abruptly westward (updip) across a north-northeast trending line through eastern Ohio. In contrast, Zagorski (1991) -- using resistivity logs across two short dip-oriented sections in northwestern Pennsylvania and adjoining Ohio-- suggests that the updip change from gas-saturated Medina Group sandstones to water-saturated sandstones is very transitional.

A map showing wells that produce or have produced water from the "Clinton" sands, the Medina sand, Medina Group sandstones, and the Tuscarora Sandstone was started for this project. In addition to showing the distribution of Lower Silurian sandstones that have high water saturations, this map may help to locate the probable updip limit of the adjoining continuous-type gas accumulation. The compilation of such a map is hindered by several factors. First, not all States require operators to document the character and quantity of water produced from oil and gas wells. Second, produced water that is reported is not always identified by stratigraphic interval. Thirdly, water-bearing parts of the Clinton/Medina interval may be intentionally cased and cemented and, thus, are not reported. Compilation of water data to date consists of recording relevant data from PI's weekly Appalachian Basin Report and plotting it by hand on a 1:500,000 scale map. Other data sources for this compilation are State Agency production files and published articles. The map is still too preliminary to indicate any definite patterns and resistivity logs have not been evaluated for evidence of high-water saturation.

BURIAL, THERMAL, AND PETROLEUM GENERATION HISTORY MODELS

Except for local CAI values for conodonts recovered from the Packer Shell and "Clinton" sands (Nancy R. Stamm, written commun. 11/18/94), thermal maturation indices are unavailable for most of the Lower Silurian sequence in the study area. In the absence of thermal maturation indices, paleotemperatures for the Clinton/Medina sandstones were estimated from burial and thermal history models calibrated with data from other stratigraphic units.

Burial, thermal, and petroleum generation history models were generated from data in six deep drill holes in Ohio and West Virginia (fig. 14). From northwest to southeast these drill holes are: 1. Pan American No. 1 Windbigler, Morrow County, Ohio; 2. Redstone No. 3 Barth, Coshocton County, Ohio; 3. Lakeshore No. 1 Marshall, Guernsey County, Ohio; 4. Amerada No. 1 Ullman, Noble County, Ohio; 5. Exxon No. 1 Deem, Wood County, West Virginia; and 6. Exxon No. 1 Gainer-Lee, Jackson County, West Virginia (fig. 14). These models provide an estimate of the thermal history in three Clinton/Medina plays (6728, 6730, 6732) and the adjoining Tuscarora Sandstone play (6727). All models assume that 5,000 ft (1.5 km) of overburden have been removed from the drill site during post-Alleghanian uplift and erosion. Thermal gradients used in the models were constrained by Rock-Eval data from the Middle Ordovician Utica Shale (Ryder and others, 1991), vitrinite analyses from Pennsylvanian strata (Chyi and others, 1987) and CAI data from selected strata (Harris and others, 1978). Because overburden removal estimates remained constant, geothermal gradients were adjusted until the calculated thermal maturity based on vitrinite kinetic reactions (BasinMod Program, Platte River Assoc., Inc.) matched the measured maturity.

The burial, thermal, and petroleum generation history model of the Amerada No. 1 Ullman drill hole is shown in figure 15. Table 4 lists the stratigraphic sequence, geochemical data, and measured thermal maturation indices used to constrain the model. Geothermal gradients

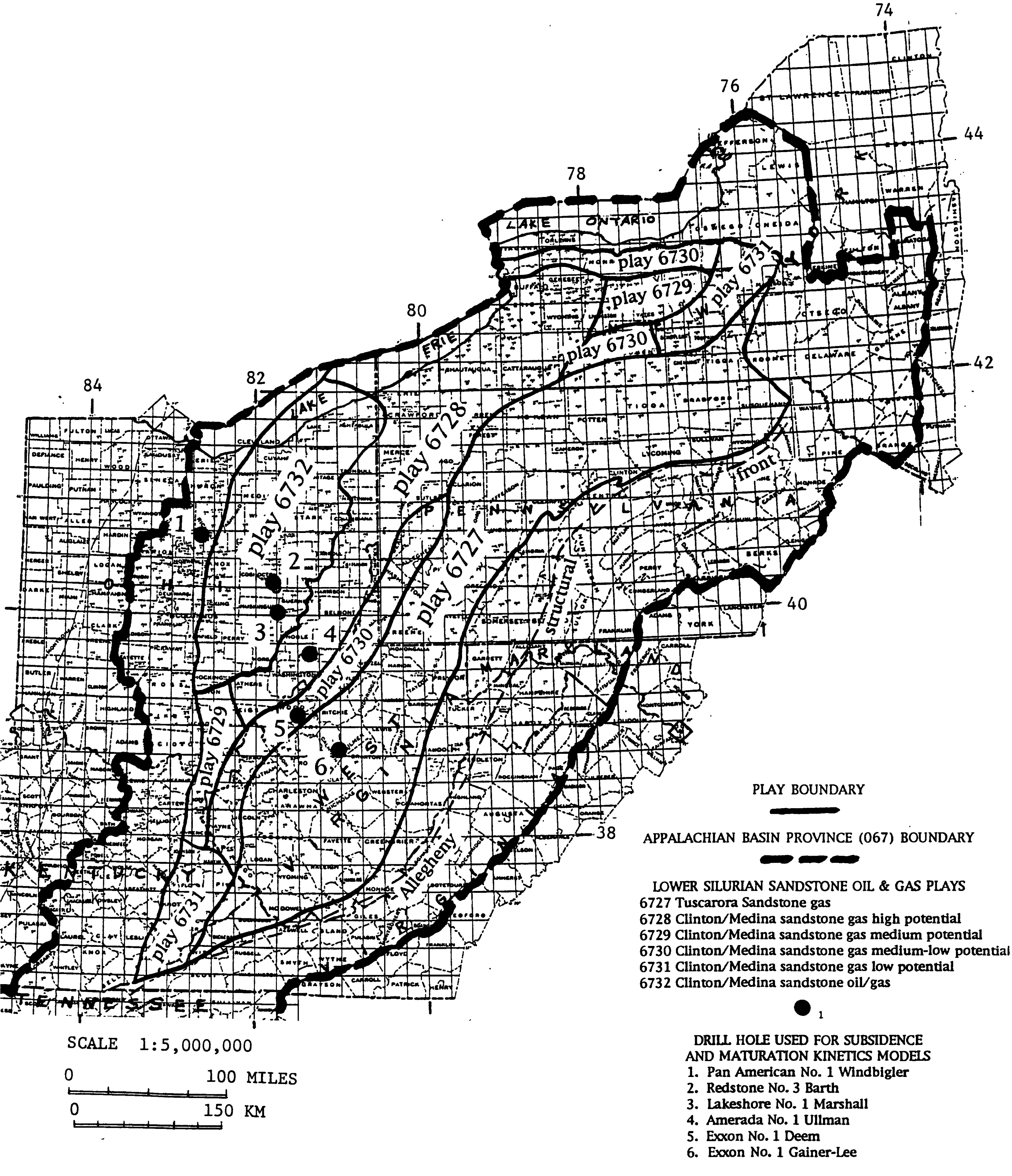

Figure 14. Map of the northern part of the Appalachian basin province (067) showing drill holes used for burial, thermal, and petroleum generation history models.

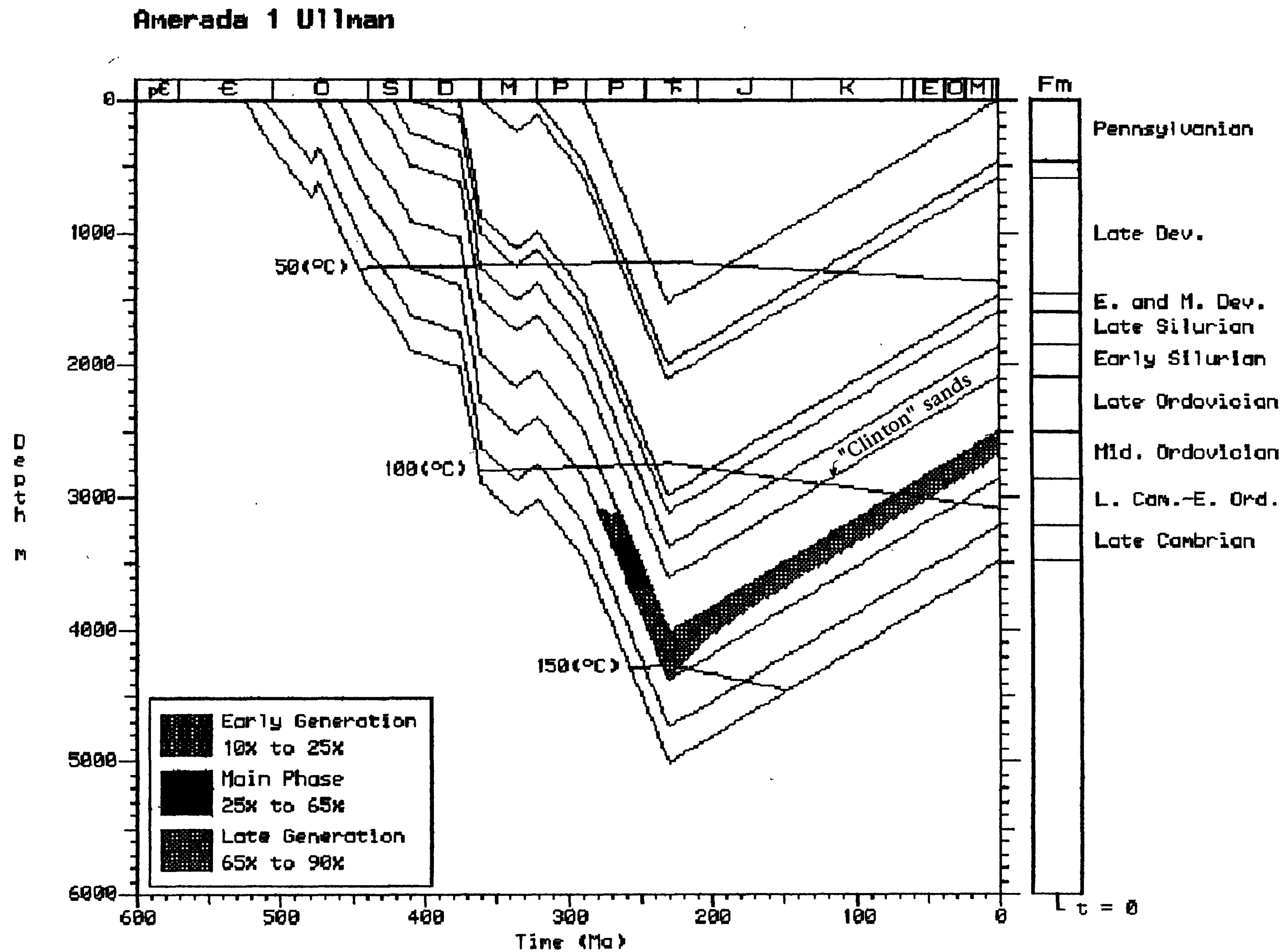

Figure 15. Burial, thermal, and petroleum generation history model for the Amerada No. 1 Ullman drill hole, Noble County, Ohio. The model was generated from the BASINMOD program. See figure 14 for location.

Amerada No. 1 Ullman
Elk Township
Noble County, Ohio
API 34-121-21278

Tops(ft)	Formation (Group)	Geochem.& Thermal Ind.	Period(Epoch)	Age(Ma)
Surface-1530	Mononghelia Group Conemaugh Group Allegheny Formation Pottsville Group ---unconformity--- ~ 400 ft removed	Ro~0.6, 100% type III kerogen	Pennsylvanian	320-288
1530-1912	Pocono Group Sunbury Shale Berea Sandstone		Mississippian	360-335
1912-4795	Upper Devonian shale and siltstone undiff.		Late Devonian	374-360
4795-5224	Marcellus Shale Columbus Limestone Oriskany Sandstone Helderberg Limestone		Early and Middle Devonian	408-374
5224-6060	Bass Islands Dolomite Salina Group		Late Silurian	421-408
6060-6835	Lockport Dolomite Rochester Shale "Clinton" sands		Early Silurian	438-421
6835-8220	Queenston Shale Reedsville Shale		Late Ordovician	458-438
8220-9382	Utica Shale-190 ft thick Trenton Limestone Black River Limestone Wells Creek Formation —Knox unconformity— ~ 350 ft removed	PI~0.03, TOC=3-4, 50% type II & 50% type III	Middle Ordovician	473-458
9382-10545	Knox Dolomite		Late Cambrian and Early Ordovician	510-478
10545-11420	Conasauga Formation Rome Formation Mt. Simon Sandstone ---unconformity---		Late Cambrian	523-510
11420	Igneous and metamorphic basement rocks		Middle Proterozoic	1,000

Table 4. Stratigraphic, geochemical, and thermal maturation indices used to constrain the subsidence and maturation kinetic model for the Amerada No. 1 Ullman, Noble County, Ohio.

required to match the modeled (calculated) maturity with the selected measured thermal maturation indices are: 1.60°F/100 ft (2.90°C/100m) for the beginning (523 Ma) and end (0 Ma) of the model and 1.80°F/100 ft (3.27°C/100m) for an Alleghanian-age heat pulse at 230 Ma. This model suggests that at maximum burial, in Early Triassic time, the "Clinton" sands in the No. 1 Ullman drill hole had reached a maximum temperature of about 250°F (120°C). The model further suggests that the main phase of oil generation in the Middle Ordovician Utica Shale, a probable source of hydrocarbons in the "Clinton" sands and Medina Group sandstones, occurred in Permian time (fig. 15). Abundant natural gas was probably generated from the Utica Shale in the vicinity of the No. 1 Ullman drill hole in early Mesozoic time as a result of the thermal cracking of oil and availability of types II and III kerogen. Fracturing by several mechanisms--basement tectonics, gas generation in the Utica Shale during maximum burial ~230 Ma, and thermoelastic expansion during post-Alleghanian uplift--may have permitted much of this natural gas to migrate vertically between 1,000 and 1,400 ft into "Clinton" sands and Medina Group sandstone reservoirs. Stable isotopic compositions of Medina Group gas in New York and Pennsylvania support the vertical migration theory (Jenden and others, 1993; Laughrey and Baldassare, 1995). Thus, the proximity of source and reservoir rocks that characterize Rocky Mountain continuous-type (basin-centered) gas accumulations may not apply to the proposed "Clinton"/Medina/Tuscarora continuous-type gas accumulation.

The required 1,000 to 1,400 ft of vertical migration, through fractured Upper Ordovician shale and siltstone, may be a deterrent to gas moving into the "Clinton"/Medina sandstones from the underlying Utica Shale. Particularly troublesome are the high formation pressures needed to displace water from the "Clinton"/Medina continuous-type accumulation. These high formation pressures may be difficult to achieve with the proposed source-to-reservoir distance.

FRACTURES AND THEIR DETECTION WITH LOG SUITES

Fractures undoubtedly play a major role in the creation of "sweet spots" in continuous-type (basin-centered) gas accumulations. Thus, data regarding the character and distribution of reservoir fractures and well-site evaluations of fracture-detection techniques would assist in the exploration, development, and assessment of the "Clinton"/Medina gas resource. Progress on these topics in FY95 was limited largely to a literature compilation on the subjects of fracture detection and evaluation, wellbore breakouts, and analysis of *in situ* stress (Appendix I, this report; Prensky, 1995). Publications by Alexander and others (1985) and Hill and others (1992) were valuable introductions to the role of fractures on gas production from the "Clinton" sands in Ohio.

SEISMIC PROFILES

Seismic profiles are of interest to this project because they may help to identify local and regional controls of tectonic fractures in the "Clinton" sands, Medina Group sandstones, and Tuscarora Sandstone. Several seismic profiles at the northeast edge of the study area are available in USGS files in Denver and numerous profiles that cross the study area are available through seismic-data brokers.

The profiles at the USGS are stored in the GEOFILE data set. They constitute 1,507 miles of single-channel (1-fold) seismic records from New York and Pennsylvania that were purchased by the USGS with limited publication rights (that is, page-size illustrations without shotpoint numbers). Although most of the lines are located too far east of the study area, some are close enough to be useful to the project. These data are old (1940's and 1950's vintage) but are of good to excellent quality. They are in digital form (8mm exabyte magnetic tape; SEG-Y format) and thus may be reprocessed. Figure 16 is an example of the typically good quality of the profiles. Profiles are available in Broome, Chemung, Schuyler, Tioga, and Tompkins Counties in New York and Bradford, Cameron, Clinton, Lycoming, Potter, and Tioga Counties in Pennsylvania.

Western Atlas and Geodata Corporations offer for purchase (with limited publication rights) other seismic profiles which cross the study area. Figure 17 is a sketch map showing the general location of lines 1-5 that were reviewed by USGS scientists. These data are 12-fold, 48-channel Vibroseis, recorded and processed in 1974. The data quality is good, especially in the northern part of the study area. Most promising is line 5 which extends from central Ashtabula County, Ohio, to the southeast corner of Mercer County, Pennsylvania. This profile crosses Henderson Dome in southeastern Mercer County (Fettke, 1950; Kuminecz and Gorham, 1993) and appears to image a highly faulted anticlinal structure. Lines 3 and 4 also show evidence of small faults and anticlines, but not to the same extent as in line 5. Geodata Corporation has access to a seismic line (P-7) that runs across Crawford and Venango Counties, Pennsylvania, northeast of, and parallel to line 5 (fig. 17). We have not yet reviewed this line. Future inquiries regarding seismic profiles in the study area will include profiles recorded in western New York State and in Lake Erie.

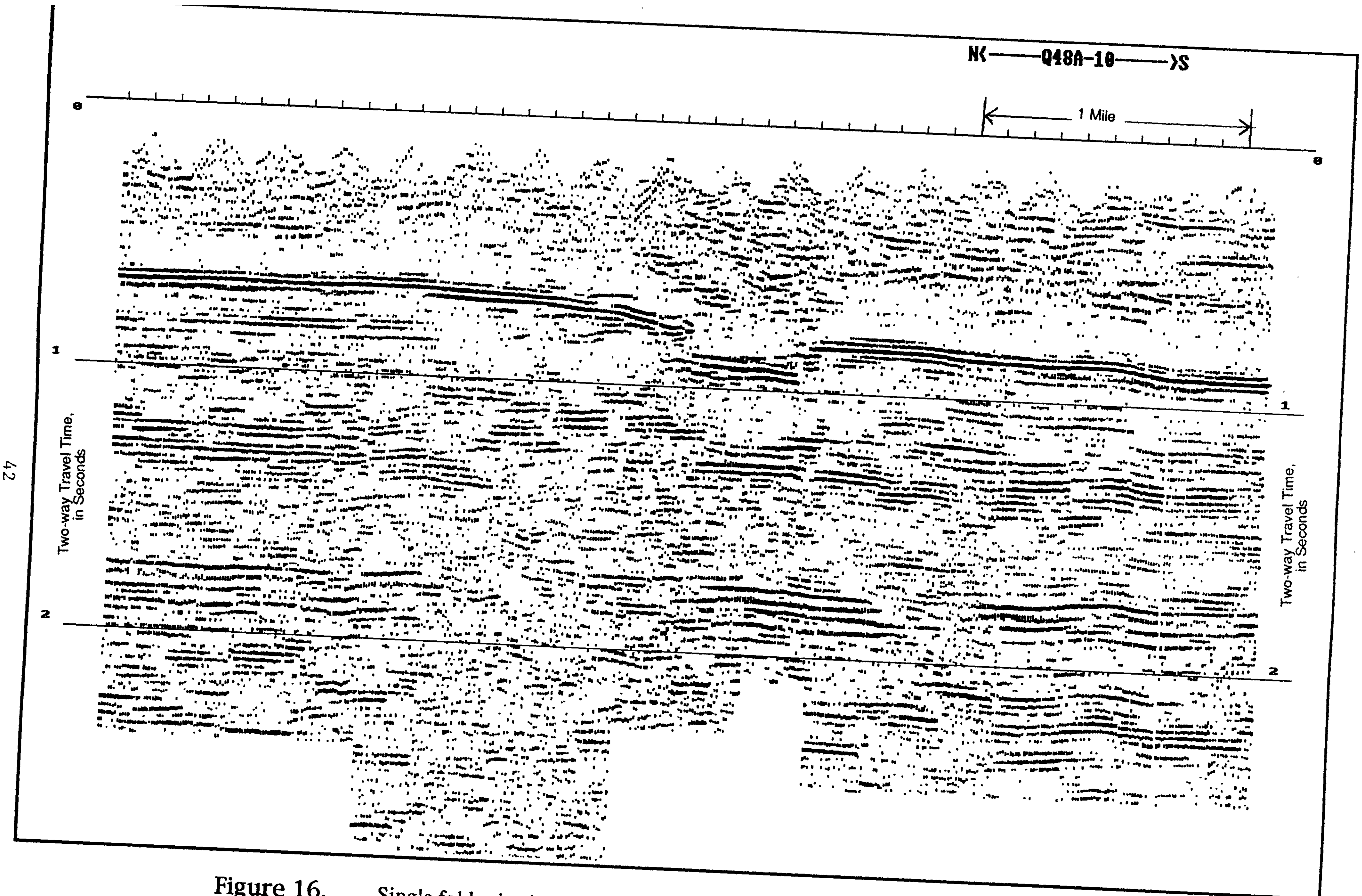

Figure 16. Single fold seismic line in Tioga County, Pennsylvania, showing typical quality of the GEOFILE data set in this area.

Figure 17. Sketch map showing the general location of seismic lines available for purchase from Western Atlas (Lines 1-5) and Geodata (Line P-7) Corporations.

ENVIRONMENTAL IMPACT ASSOCIATED WITH DEVELOPMENT OF CONTINUOUS GAS ACCUMULATIONS

The high drilling density required to develop continuous gas accumulations can have a great impact on the environment. Visual impacts related to dense well spacing include those created by access roads, pipelines, and well locations. In many cases, the amount of land disturbed can be minimized through the early identification of the accumulation type and size. First, a well-designed access and transportation network should be planned in advance. Where several operators are developing the accumulation, a cooperative planning and construction effort is desirable to reduce visual impact and costs. Secondly, surface impact can be reduced by having several wells share a single-well location. Having multiple wells at a single location is accomplished by directional drilling techniques. Also, visual impact can be reduced by locating well sites, roads, and pipelines in areas that are visible only over short distances such as in ravines and behind small hills.

Water production may be associated with continuous gas accumulations but it is low in comparison to that in conventional and coalbed gas accumulations. This water production, which generally is less than 10 barrels of water a day for the Clinton/Medina sandstone reservoirs, must be disposed of in a safe and economical manner. The free water is separated from the gas stream by a separator whereas molecular water is commonly separated from the gas stream by glycol dehydration. Current disposal methods include reinjecting the water, evaporation, creating wetlands, or hauling it to a treatment plant. The amount and quality of the water dictate the method used. Reinjecting the water is accomplished either by using a nonproducing well, or drilling a new well. The water may be reinjected into the same formation from which it was produced or into a different formation that is isolated from water aquifers used for domestic, agricultural, or industrial purposes. In some areas, the water is discharged into the local drainage system and, in at least one case, in the Green River Basin of Wyoming, it is used to create a wetland. Also, the water can be stored in tanks at the well site and hauled to a common treatment and disposal site.

A study by Callaway (1987) indicates that in New York State there is little between-well variation in the quality of formation water produced from a given reservoir. Forty-six of the eighty-six water samples used in the study were collected from Medina Group sandstones. Previous studies indicating significant between-well variation in the quality of formation water were based on a large number of samples, many of which were inconsistently sampled and analyzed. For example, analyses from numerous labs failed to meet basic ionic and mass balance checks. Water samples utilized by Callaway (1987) indicate that 98% of their dissolved solids, ranging from 10,000 to 25,000 ml/l, are accounted for by sodium, calcium, magnesium, potassium, and chloride. The addition of barium and strontium to this list of elements accounts for over 99% of the dissolved solids. Similar high dissolved solids and chemical constituents are recorded in formation waters in Medina Group sandstones in Pennsylvania (Young and others, 1991; Siegel and others, 1990) and "Clinton" sands in Ohio (Breen and others, 1985).

SUMMARY OF FY95 ACCOMPLISHMENTS

1. Three regional transects have been drawn through selected parts of New York, Ohio, and Pennsylvania to show the stratigraphic, facies, and sequence stratigraphic framework of the Niagaran Series (Medina, Clinton, and Lockport Groups and equivalent strata).
2. New facies and sequence stratigraphic interpretations are suggested for sandstones of the Medina Group in western New York State. One new interpretation is the sequence boundary within the Grimsby Formation. This proposed sequence boundary resulted from broad valleys cut into emergent, progradational shoreface sandstone (highstand tract deposits) and backfilled by fluvial and tidal sandstone (transgressive tract deposits) during a rise in sea level.
3. Several thousands of gas production records for individual wells have been acquired in digital form for six counties in New York and five counties in Pennsylvania. These production records are stored on the USGS Wells database.
4. A land-use and land-cover map with political boundaries was compiled at a scale of 1:500,000. Also included on the map are boundaries of Clinton/Medina/Tuscarora oil and(or) gas plays and 1/4 sq mi cells showing the distribution of wells that penetrate the Clinton/Medina/Tuscarora interval and their hydrocarbon status.
5. An oil and gas field map was compiled for the "Clinton" sands, Medina Group sandstones, and Tuscarora Sandstone at a scale of 1:500,000.
6. A preliminary map showing structural contours has been constructed for the study area at a scale of 1:500,000 using the Dynamic Graphics Inc. Interactive Surface Modeling (ISM) system and WHCS data files.
7. A comprehensive literature search was made for structure below the Upper Silurian Salina Group salt in the play area to identify potential

structural elements that may control fracture patterns in Clinton/Medina sandstone reservoirs.

8. A working hypothesis suggests that the Clinton/Medina sandstones and the equivalent Tuscarora Sandstone in the Appalachian basin should have three pressure domains; a normally pressured domain, a low-pressured domain, and a high-pressured domain. The normal and underpressured domains have been verified by project investigations in FY95. The postulated overpressured domain has yet to be verified but there are some indications that the Tuscarora Sandstone reservoirs in central Pennsylvania may be overpressured.

9. Wells that produce or have produced water from the "Clinton" sands, Medina sand, Medina Group sandstones, and Tuscarora Sandstone were compiled on a preliminary map. These maps will be used to better define the boundary between continuous-type and discrete hydrocarbons accumulations in the Clinton/Medina sandstone reservoirs.

10. Several hundred published and unpublished analyses for brines and formation waters in the Clinton/Medina sandstone reservoirs were compiled and loaded into a USGS database.

11. Burial, thermal, and petroleum generation history models were generated from data in six deep drill holes in Ohio and West Virginia to estimate paleotemperatures of the "Clinton" sands and Tuscarora Sandstone and to test the feasibility of the Middle Ordovician Utica Shale as the source of the gas in the "Clinton"/Medina/Tuscarora interval. These models suggest that the Utica Shale, located 1,000 to 1,400 ft beneath the Clinton/Medina/Tuscarora sandstones, is a plausible source of the gas.

12. Seismic profiles were located in New York, Ohio, and Pennsylvania that may help to identify local and regional structures capable of generating tectonic fractures in the "Clinton" sands, Medina Group, and Tuscarora Sandstone .

13. Environmental issues were investigated to evaluate the impact of high drilling density and local brine disposal associated with extracting gas from a continuous-type accumulation.

14. An extensive selected bibliography was compiled for literature regarding the geology and oil and gas resources of the "Clinton" sands, Medina Group, and Tuscarora Sandstone in the Appalachian basin.

15. The preliminary results of this project generally support the Lower Silurian Clinton/Medina/Tuscarora sandstone plays as defined for the 1995 National Assessment and the assessment methodology applied to them.

  a. The characterization of the Clinton/Medina sandstone gas plays (6728-6731) in the 1995 National Assessment as a part of a continuous-type gas accumulation is justified. Moreover, the assessment methodology applied to these plays--which accounts for regionally extensive, gas-saturated reservoirs--is appropriate.

b. The Clinton/Medina sandstone oil/gas play (6732) in the 1995 National Assessment, that adjoins the continuous-type gas accumulation plays on the west, seems to be appropriately defined as a conventional oil and gas play having discrete accumulations. However,the trapping mechanism(s) of the oil and gas in the conventional play and the limits of the transitional boundary between the conventional and continuous-type (unconventional) plays remain poorly known.

c. The Tuscarora Sandstone gas play (6727) in the 1995 National Assessment, that adjoins the continuous-type gas plays on the east, may need to be revised. Sparse pressure and temperature data suggest that this play may be a continuous-type gas play rather than a conventional gas play as originally suggested in the 1995 National Assessment. More data are needed to support the new interpretation.

REFERENCES CITED

Alexander, R., Biddison, J.M., Brannock, M., Reyher, S., Scheper, R., Smith, R., Shafer, W., Maslowski, A., and Shafer, M., 1985, Clinton panel discussion 1985, in The New Clinton Collection, Ohio Geological Society, Columbus, p. 3-18

Avary, K.L., in press, Play Sts: The Lower Silurian Tuscarora Sandstone fractured anticlinal play, in Roen, J.B. and Walker, B., eds., Atlas of major Appalachian gas plays: U.S. Department of Energy, Gas Research Institute, and Appalachian Oil and Natural Gas Research Consortium.

Beeman, W.R., 1995, Development and use of a Geographic Information System (GIS) for resource appraisal, in Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1995 national assessment of United States oil and gas resources--Results, methodology, and supporting data: U.S. Geological Survey Digital Data Series DDS-30, 10 p.

Breen, K.J., Angelo, C.G., Masters, R.W., and Sedam, A.C., 1985, Chemical and isotopic characteristics of brines from three oil- and gas-producing sandstones in eastern Ohio, with applications to the geochemical tracing of brine sources: U.S. Geological Survey Water Resources Investigations Report No. 84-4314, 63 p.

Brett, C.E., Goodman, W.M., and LoDuca, S.T., 1990, Sequences, cycles, and basin dynamics in the Silurian of the Appalachian foreland basin: Sedimentary Geology, v.69, no.3/4, p. 191-244.

Brett, C.E., Tepper, D.H., Goodman, W.M., LoDuca, S.T., and Eckert, B.-Y., 1995, Revised stratigraphy and correlations of the Niagaran Provincial Series (Medina, Clinton, and Lockport Groups) in the type area of western New York: U.S. Geological Survey Bulletin 2086, 66 p.

Callaway, T.M., 1987, Preliminary produced brine study: New York State Department of Environmental Conservation Administrative report, Albany, NY, 5 p.

Cate, A.S., 1961, Stratigraphic studies of the Silurian of Pennsylvania, part 1, stratigraphic cross sections of Lower Devonian and Silurian rocks of western Pennsylvania and adjacent areas: Pennsylvania Topographic and Geologic Survey Special Bulletin 10, 3 p., 5 plates.

Chyi, L.L., Barnett, R.G., Burford, A.E., Quick, T.J., and Gray, R.J.., 1987, Coalification patterns of the Pittsburgh coal: Their origin and bearing on hydrocarbon maturation: International Journal of Coal Geology, v. 7, no. 1, p. 69-83.

Coogan, A.H., 1991, A fault-related model for the facies of the Lower Silurian Clinton Sandstone interval in the subsurface of eastern Ohio: Northeastern Geology, v. 13, no. 2, p. 110-129.

Cotter, E., 1983, Shelf, paralic, and fluvial environments and eustatic sea-level fluctuations in the origin of the Tuscarora Formation (Lower Silurian) of central Pennsylvania: Journal of Sedimentary Petrology, v. 53, no. 1, p. 25-49.

Davis, T.B., 1984, Subsurface pressure profiles in gas-saturated basins, in Masters, J.A., ed., Elmworth--Case study of a deep basin gas field: American Association of Petroleum Geologists Memoir 38, p. 189-203.

DeBrosse, T.A. and Vohwinkel, J.C., 1974, Oil and gas fields of Ohio: Ohio Division of Geological Survey in cooperation with Ohio Division of Oil and Gas, 1 sheet, scale 1:500,000.

deWitt, W., 1993, Principal oil and gas plays in the Appalachian basin (province 131): U.S. Geological Survey Bulletin 1839-I, 37 p.

deWitt, W., Perry, W.J., Jr., and Wallace, L.G., 1975, Oil and gas data from Devonian and Silurian rocks in the Appalachian basin: U.S. Geological Survey Miscellaneous Investigations Map I-917B.

Fettke, C.R., 1950, Henderson dome, a unique structure in northwestern Pennsylvania: Geological Society of America Bulletin (abs.), v. 61, no. 12, pt. 2, p. 1458.

Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1995, 1995 national assessment of United States oil and gas resources--Results methodology, and supporting data: U.S. Geological Survey Digital Data Series DDS-30.

Gray, J., Maslowski, A., McCullough, W. and Shafer, W.E.., 1985, The new Clinton collection 1985 (reprinted 1987 with one additional paper): Ohio Geological Society, Columbus, Ohio, 257 p.

Harris, A.G., Harris, L.H., and Epstein, J.B., 1978, Oil and gas data from Paleozoic rocks in the Appalachian basin: maps for assessing hydrocarbon potential and thermal maturity (conodont color alteration isograds and overburden isopachs): U.S. Geological Survey Miscellaneous Investigations Map I-917E, 4 sheets, scale 1:2,500,000.

Hettinger, R.D., McCabe, P.J., and Shanley, K.W., 1994, Detailed facies anatomy of transgressive and highland systems tracts from the Upper Cretaceous of southern Utah, U.S.A., in Posamentier, H.W. and Weimer, P., eds., Recent advances in siliciclastic sequence stratigraphy: American Association of Petroleum Geologists Memoir 58, p. 235-257.

Hill, R.E., Kukal, G.C., Middlebrook, M., and Peterson, R.E., 1992, Geological, petrophysical and engineering analysis of the Clinton Sandstone–Belden & Blake Corporation Central Waste No.12 Mahoning County, Ohio: Gas Research Institute, Chicago, GRI Contract No. 5091-212-2242 to CER Corporation, 45 p.

Jenden, P.D., Drazan, D.J., and Kaplan, I.R., 1993, Mixing of thermogenic natural gases in northern Appalachian basin: American Association of Petroleum Geologists Bulletin, v. 77, no. 6, p. 980-998.

Keltch, B., 1985, Depositional systems and reservoir quality of the Clinton sandstone, Guernsey County, Ohio: Unpublished M.S. thesis, University of Cincinnati, 72 p.

Knight, W.V., 1969, Historical and economic geology of Lower Silurian Clinton Sandstone of northeastern Ohio: American Association of Petroleum Geologists Bulletin, v. 53,no. 7, p. 1421-1452.

Kuminecz, C.P. and Gorham, S.B., 1993, Henderson Dome: A hydrocarbon-producing, basement-involved structural anomaly of the Coshocton zone, Mercer County, western Pennsylvania, in Catacosinos, P. and others, conveners, Basement and basins of eastern North America: American Association of Petroleum Geologists Hedberg Reasearch Conference Proceedings [Ann Arbor, Mich., Nov. 10-13, 1993], 2 p.

Laughrey, C.D., 1984, Petrology and reservoir characteristics of the Lower Silurian Medina Group sandstones, Athens and Geneva fields, Crawford County, Pennsylvania: Pennsylvania Topographic and Geologic Survey Mineral Resource Report 85, 126 p.

Laughrey, C.D. and Baldassare, F., 1995, Geochemistry and origin of some natural gases in the Plateau Province of the central Appalachian basin, Pennsylvania and Ohio (abs.): American Association of Petroleum Geologists Bulletin, v. 79, no. 9, p. 1416.

Law, B.E. and Dickinson, W.W., 1985, Conceptual model for origin of abnormally pressured gas accumulations in low-permeability reservoirs: American Association of Petroleum Geologists Bulletin, v. 69, no. 8, p. 1295-1304.

Law, B.E. and Spencer, C.W., 1993, Gas in tight reservoirs-An emerging major source of energy, in Howell, D.G., ed., The future of energy gases: U.S. Geological Survey Professional Paper 1570, p. 233-252

Law, B.E., Spencer, C.W., Charpentier, R.R., Crovelli, R.A., Mast, R.F., Dolton, G.L., and Wandrey, C.J., 1989, Estimates of gas resources in overpressured low-permeability Cretaceous and Tertiary sandstone reservoirs, greater Green River Basin, Wyoming, Colorado, and Utah, in Eisert, J.L., ed., Gas resources of Wyoming: Wyoming Geological Association Guidebook for the 40th Field Conference, p. 39-61.

Mast, R.F., Dolton, G.L., Crovelli, R.A., Root, D.H., Attanasi, E.D., Martin, P.E., Cooke, L.W., Carpenter, G.B., Pecora, W.C., and Rose, M.B., 1989, Estimates of undiscovered conventional oil and gas resources in the United States-A part of the Nation's energy endowment: U.S. Geological Survey and Mineral Management Service publication, U.S. Department of Interior, Washington, D.C., 44 p.

Masters, J.A., 1979, Deep basin gas trap, western Canada: American Association of Petroleum Geologists Bulletin, v. 63, no. 2, p. 152-181.

____________, 1984, Elmworth--Case study of a deep basin gas field: American Association of Petroleum Geologists Memoir 38, 316 p.

Metzger, S.L., 1981, A subsurface study and paleo-environmental analysis of the Medina group, Chautauqua County, New York: unpublished M.S thesis, The State University College, Fredonia, New York, 102 p.

Middleton, G.V., Rutka, M., and Salas, C.J., 1987, Depositional environments in the Whirlpool Sandstone Member of the Medina Formation, in Duke, W.L., ed., Sedimentology, stratigraphy, and ichnology of the Lower Silurian Medina Formation in New York and Ontario: Society of Economic Paleontologists and Mineralogists, Eastern Section, 1987 Annual Field Trip Guidebook, p. 31-45.

Osten, M.A., 1982, The subsurface stratigraphy, paleoenvironmental interpretation and petroleum geology of the Albion Group (Lower Silurian), southeast Ohio: unpublished M.S. thesis, Kent State University, Kent, Ohio, 166 p., 13 plates

Pees, S.T., 1983, Model area describes NW Pennsylvania's Medina play: Oil and Gas Journal, (pt. 1), v. 81, no. 21, p. 55-60; (pt. 2), v. 81, no. 22, p. 98-102.

Pepper, J.F., deWitt, W., Jr., and Everhart, G.M., 1953, Oil and gas geology of the "Clinton" sands of Ohio: U.S. Geological Survey Bulletin 1003-A, 15 p.

Perry, K., 1994, Tight gas sands production: past-present-future: In Focus--Tight Gas Sands, v. 10, no. 1, p. 1-12.

Piotrowski, R.G., 1981, Geology and natural gas production of the Lower Silurian Medina Group and equivalent rock units in Pennsylvania: Pennsylvania Topographic and Geologic Survey Mineral Resource Report 82, 21 p., 11 plates.

Prensky, S. E., 1995, Bibliography of well-log applications cumulative edition to September 30, 1994 [computer file]: U.S. Geological Survey Open-File Report 95-0064C, disk.

Rodgers, M.R. and Anderson, T.H., 1984, Tyrone-Mt. Union cross-strike lineament of Pennsylvania: A major Paleozoic basement fracture and uplift boundary: American Association of Petroleum Geologists Bulletin, v. 68, no. 1, p. 92-105.

Rose, P.R., Everett, J.R., and Merin, I.S., 1984, Possible basin centered gas accumulation, Raton basin, southern Colorado: Oil and Gas Journal, October 1, 1984, p. 190-192, 194, 196-197.

Russell, W.L., 1972, Pressure-depth relations in Appalachian region: American Association of Petroleum Geologists Bulletin, v. 56, no. 3, p. 528-536.

Ryder, R.T., 1995, Appalachian basin province (067), in Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1995 national assessment of United States oil and gas resources--Results, methodology, and supporting data: U.S. Geological Survey Digital Data Series DDS-30, 144 p., 28 figs.

Ryder, R.T., Burruss, R.C., and Hatch, J.R., 1991, Geochemistry of selected oil and source rock samples from Cambrian and Ordovician strata, Ohio-West Virginia-Tennessee part of the Appalachian basin: U.S. Geological Survey Open-File Report 91-434, 71 p.

Schmoker, J., 1995a, Continuous hydrocarbon reservoirs: Selected Issues in the USGS Energy Resource Surveys Program: U.S. Geological Survey, August 1995, 2 p.

Schmoker, J.W., 1995b, Method for assessing continuous-type (unconventional) hydrocarbon accumulations, in Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1995 national assessment of United States oil and gas resources--Results, methodology, and supporting data: U.S. Geological Survey Digital Data Series DDS-30, 17 p., 7 figs.

Shanley, K.W. and McCabe, P.J., 1991, Predicting facies architecture through sequence stratigraphy--An example from the Kaiparowits Plateau, Utah: Geology, v. 19, no. 7, p. 742-745.

Siegel, D.I., Szustakowski, R.J., and Frape, S., 1990, Regional appraisal of brine chemistry in the Albion Group sandstones (Silurian) of New York, Pennsylvania, and Ohio: Bulletin of the Association of Petroleum Geochemical Explorationists: v. 6, no. 1, p. 66-77.

Spencer, C.W., 1989, Review of characteristics of low-permeability gas reservoirs in western United States: American Association of Petroleum Geologists Bulletin, v. 73, no. 5, p. 613-629.

Thomas, M.A., 1993, Subnormal fluid pressure in the Clinton sandstone of eastern Ohio: unpublished Ph.D. thesis, Kent State University, 111 p.

Wheeler, R.L., 1980, Cross-strike structural discontinuities: Possible exploration tool for natural gas in the Appalachian overthrust belt: American Association of Petroleum Geologists Bulletin, v. 64, no. 12, p. 2166-2178.

Young, K.G., Waite, B.A., and Moody, J.L., 1991, Oil and gas well pollution abatement project: Pennsylvania Department of Environmental Resources Report ME 81495, pts. A and B, Meadville, PA, 12 p.

Zagorski, W.A., 1988, Exploration concepts and methodology for deep Medina sandstone reservoirs in northwestern Pennsylvania (abs.): American Association of Petroleum Geologists Bulletin, v. 72, no. 8, p. 976.

____________, 1991, Model of local and regional hydrocarbon traps in the Lower Silurian Medina Sandstone Group, Cooperstown gas field, Crawford and Venango Counties, Pennsylvania: unpublished M.S. thesis, University of Pittsburgh, 132 p.

APPENDIX I

Selected bibliography of the geology and oil and gas resources of the Lower Silurian "Clinton" sands, Medina Group sandstones, and Tuscarora Sandstone, Appalachian basin of New York, Ohio, Pennsylvania, and West Virginia
(as of October 1, 1995)

Beinkafner, K.J., 1983, Deformation of the subsurface Silurian and Devonian rocks of the southern tier of New York State: unpublished Ph.D. thesis, Syracuse University, 481 p.

Boswell, R., Pool, S., Pratt, S., and Matchen, D., 1993, Appalachian basin low permeability sandstone reservoir characterizations: Report 94CC-R91-003, U.S. Department of Energy contract DE-AC21-90MC26328, Morgantown Energy Technology Center, Morgantown, West Virginia, 73 p.

Brett, C.E., Goodman, W.M., and LoDuca, S.T., 1990, Sequences, cycles, and basin dynamics in the Silurian of the Appalachian foreland basin, in Aigner, T. and Dott, R.H., eds., Processes and patterns in epeiric basins: Sedimentary Geology, v. 69, p. 191-244.

Brett, C.E., Tepper, D.H., Goodman, W.M., LoDuca, S.T., and Eckert, B., 1995, Revised stratigraphy and correlations of the Niagaran Provincial Series (Medina, Clinton, and Lockport Groups) in the type area of western New York: U.S. Geological Survey Bulletin 2086, 66 p.

Callaway, T.M., 1987, Preliminary produced brine study: New York State Department of Environmental Conservation Administrative report, Albany, NY, 5 p.

Castle, J.W., 1991, Sequence stratigraphy and depositional systems of the Lower Silurian Medina Group, Appalachian basin (abs.): American Association of Petroleum Geologists Bulletin, v. 75, no. 8, p. 1380.

Copley, D.L., 1979, Medina gas production in Chautaque[sic] County, New York: Technical Paper No. 5, 18th Annual Conference of Ontario Petroleum Institute Inc.,[Chatham, Ontario, Oct. 15, 1979], p. 1-17.

___________, 1980, Upgrading Medina gas well production in western New York: World Oil, v.190, no.5, p. 97-106

Davis, R.J. and Johnson, C.A., 1992, Stratigraphic-dipmeter interpretation of depositional systems in the Lower Silurian Medina Group of western New York improves offset well success: Log Analyst, v. 33, no. 2, p. 111-125.

Davis, R.J., Johnson, C.A., and Gilreath, J.A., 1990, Interpretation of depositional systems in the Lower Silurian Medina Group of western New York: 31st Annual SPWLA Logging Symposium Transactions, v. 1, paper no. N, 25 p.

Division of Mineral Resources, New York State Department of Environmental Conservation, 1986, New York State oil and gas fields: Division of Mineral Resources, New York State Department of Environmental Conservation Map, 1 sheet, 1:250,000.

________________________, 1994, 1993 New York State oil and gas drilling and production--Cattaraugus County profile: Division of Mineral Resources, New York Department of Environmental Conservation, 10 p.

________________________, 1994, 1993 New York oil and gas drilling and production--Chautauqua County profile: Division of Mineral Resources, New York Department of Environmental Conservation, 10 p.

________________________, 1994, 1993 New York State oil and gas drilling and production--Erie County profile: Division of Mineral Resources, New York Department of Environmental Conservation, 10 p.

Duke, W.L., 1987, Revised internal stratigraphy of the Medina Formation in outcrop--an illustration of the inadequacy of color variation as a criterion for lithostratigraphic correlation, in Duke, W.L., ed., Sedimentology, stratigraphy, and ichnology of the Lower Silurian Medina Formation in New York and Ontario: Society of Economic Paleontologists and Mineralogists, Eastern Section, 1987 Annual Field Trip Guidebook, p. 16-30.

__________, 1991, Part 4, The Lower Silurian Medina Group in New York and Ontario, in Cheel, R.J., ed., Sedimentology and depositional environments of Silurian strata of the Niagara Escarpment, Ontario and New York: Sudbury, Ontario, Geological Association of Canada, Mineralogical Association of Canada, Society of Economic Geologists, Joint Annual Meeting, Field Trip B4 Guidebook, p. 35-61.

Duke, W.L., Fawcett, P.J., and Brusse, W.C., 1991, Prograding shoreline deposits in the Lower Silurian Medina Group, Ontario and New York– storm- and tide-influenced sedimentation in a shallow epicontinental sea, and the origin of enigmatic shore-normal channels encapsulated by open shallow-marine deposits: Special Publications of the International Association of Sedimentologists, v. 14, p. 339-375.

Fisher, D.W., 1954, Stratigraphy of Medinan Group, New York and Ontario: American Association of Petroleum Geologists Bulletin, v. 38, no. 9, p. 1979-1996.

__________, 1959, Correlation of the Silurian rocks in New York State: New York State Museum and Science Service , University of the State of New York, and New York Geological Survey Chart, 1 sheet

Hamak, J.E. and Sigler, S., 1991, Analyses of natural gases, 1986-1990: U.S. Bureau of Mines Information Circular IC 9301, 315 p.

Jenden, P.D., Drazan, D.J., and Kaplan, I.R., 1993, Mixing of thermogenic natural gases in northern Appalachian basin: American Association of Petroleum Geologists Bulletin, v. 77, no. 6, p. 980-998.

Ji, F. and Robinson, J.E., 1990, The Medina Formation in New York State, a computer assisted study utilizing an integrated data base, in Shumaker, R.C., compiler, Appalachian Basin Industrial Associates, v. 17, West Virginia University, Morgantown, p. 169-183.

Kearney, M.W., 1983, Subsurface geology of the Silurian Medina and Clinton Groups, New York State: unpublished M.S. thesis, Southern Methodist University, Dallas, Texas, 121 p.

Kriedler, W.L., 1963, Selected deep wells and areas of gas production in western New York: New York State Museum and Science Service Bulletin 390, 404 p.

Kreidler, W.L., Van Tyne, A.M., and Jorgensen, K.M., 1972, Deep wells in New York State: New York State Museum and Science Service Bulletin 418A, 335 p.

Lumsden, D.N. and Pelletier, B.R., 1969, Petrology of the Grimsby Sandstone (Lower Silurian) of Ontario and New York: Journal of Sedimentary Petrology, v. 39, no. 2, p. 521-530.

Martini, I.P., 1971, Regional analysis of sedimentology of Medina Formation (Silurian), Ontario and New York: American Association of Petroleum Geologists Bulletin, v. 55, p. 1249-1261.

Metzger, S.L., 1981, A subsurface study and paleo-environmental analysis of the Medina group, Chautauqua County, New York: unpublished M.S. thesis, The State University College, Fredonia, New York, 102 p.

Metzger, W.J., 1980, Medina gas well decline curves, Chautauqua County, New York (abs.): in 11th Annual Petroleum Geology Symposium: Current Research and Exploration in the Appalachian Basin [Morgantown, WV, March 31-April 2, 1980]: West Virginia Geologic and Economic Survey Circular C-16, p. 15

Middleton, G.V., 1987, Geologic setting of the northern Appalachian basin during the Silurian, in Duke, W.L., ed., Sedimentology, stratigraphy, and ichnology of the Lower Silurian Medina Formation in New York and Ontario: Society of Economic Paleontologists and Mineralogists, Eastern Section, 1987 Annual Field Trip Guidebook, p. 1-15.

Middleton, G.V., Rutka, M., and Salas, C.J., 1987, Depositional environments in the Whirlpool Sandstone Member of the Medina Formation, in Duke, W.L., ed., Sedimentology, stratigraphy, and ichnology of the Lower Silurian Medina Formation in New York and Ontario: Society of Economic Paleontologists and Mineralogists, Eastern Section, 1987 Annual Field Trip Guidebook, p. 31-45.

Moore, B.J., 1982, Analyses of natural gases, 1917-1980: U.S. Bureau of Mines Information Circular 8870, 1055 p.

Poppendeck, M.C., 1979, Subsurface petroleum study of the Medina Sandstones (Silurian), southwestern Chautauqua County, New York: unpublished M.S. thesis, State University of New York at Buffalo, 37 p.

Raven, K.G., Novakowski, K.S., Yager, R.M., and Heystee, R.J., 1992, Supernormal fluid pressures in sedimentary rocks of southern Ontario-western New York State: Canadian Geotechnical Journal, v. 29, no. 1, p. 80-93.

Radon, S.F., 1987, The Medina Group (Lower Silurian) of western New York, with emphasis on the "White Facies" of the Grimsby Sandstone: unpublished M.S. thesis, Kent State University, Kent, Ohio, 170 p.

Rickard, L.V., 1975, Correlation of Silurian and Devonian rocks in New York State: New York State Museum and Science Service Map and Chart Series 24, 16 p., 4 plates

Robinson, J.E., 1987, Upper Ordovician and Silurian sandstone facies of central New York State, in Misra, K., compiler, Appalachian Basin Industrial Associates, v. 12, University of Tennessee, Knoxville, p. 93-106.

Shyer, E.B., 1989, Historical digest: Medina sandstone, in New York State Oil and Gas Drilling and Production 1988: Division of Mineral Resources, New York State Department of Environmental Conservation, p. 27-33.

Siegel, D.I., Szustakowski, R.J., and Frape, S., 1990, Regional appraisal of brine chemistry in the Albion Group sandstones (Silurian) of New York, Pennsylvania, and Ohio: Bulletin of the Association of Petroleum Geochemical and Explorationists, v. 6, no. 1, p. 66-77.

Statistics Task Group Underground Storage Committee, 1988, Survey of underground gas storage facilities in the United States and Canada 1988: American Gas Association Report, Arlington, VA, (New York part) p. 34-37.

The Appalachian Company, 1982, Tight gas sands determination report in New York State: Division of Mineral Resources, New York State Department of Environmental Conservation, several hundred pages (variously paginated).

Van Tyne, A.M. and Copley, D.L., 1984, Estimates of potential natural gas reserves in New York as of December 31, 1983: Independent Oil and Gas Association of New York, 61 p., 8 plates.

CLINTON/MEDINA BIBLIOGRAPHY (OHIO)

Alexander, R., Biddison, J.M., Brannock, M., Reyher, S., Scheper, R., Smith, R., Shafer, W., Maslowski, A., and Shafer, M., 1985, Clinton panel discussion 1985, in The New Clinton Collection, Ohio Geological Society, Columbus, p. 3-18

Austin, J.M., 1979, The subsurface stratigraphy and petroleum geology of the "Clinton" sandstone, northern Portage County, northeastern Ohio: unpublished M.S. thesis, Kent State University, Kent, Ohio, 90 p.

Bakush, S.H., 1975, A review of the Clinton Sandstone in east central Ohio (Coshocton, Guernsey, Knox, Licking, Muskingum, and Noble Counties): unpublished M.S. thesis, Ohio University, 49 p.

Belden, H., 1952, Canton gas pool: Ohio Division of Geological Survey Report of Investigations 13, p. 59-70.

Boley, D.W., Johnson. H.R., and Overby, W.K., 1965, Oil reservoir analysis and predicted recovery by water flooding, "Clinton" sand, Logan oilfield, Hocking County, Ohio: U.S. Bureau of Mines Report of Investigations 6683, 43 p.

Bonine, P.H., 1915, Anticlines in the Clinton Sandstone near Wooster, Wayne County, Ohio, in Contributions to Economic Geology, part II: U.S. Geological Survey Bulletin 621-H, p. 87-98.

Boswell, R., Pool, S., Pratt, S., and Matchen, D., 1993, Appalachian basin low permeability sandstone reservoir characterizations: Report 94CC-R91-003, U.S. Department of Energy contract DE-AC21-90MC26328, Morgantown Energy Technology Center, Morgantown, West Virginia, 73 p.

Breen, K.J., Angelo, C.G., Masters, R.W., and Sedam, A.C., 1985, Chemical and isotopic characteristics of brines from three oil- and gas-producing sandstones in eastern Ohio, with applications to the geochemical tracing of brine sources: U.S. Geological Survey Water Resources Investigations Report No. 84-4314, 63 p.

Brown, P.H., 1979, The geology of the Lower Silurian Albion Group of Mahoning County, Ohio, unpublished M.S. thesis, Kent State University, Kent, Ohio, 90 p.

Castle, J.W., 1991, Sequence stratigraphy and depositional systems of the Lower Silurian Medina Group, Appalachian basin (abs.): American Association of Petroleum Geologists Bulletin, v. 75, no. 8, p. 1380.

Cole, G.A., Drozd, R.J., Sedivy, R.A., and Halpern, H.I., 1987, Organic geochemistry and oil-source correlations, Paleozoic of Ohio: American Association of Petroleum Geologists Bulletin, v. 71, no. 7, p. 788-809.

Coogan, A.H., 1990, Whirlpool (Early Silurian) marine transgression in eastern Ohio: Northeastern Geology, v. 12, no. 3, p. 138-142.

___________, 1991, A fault-related model for the Lower Silurian Clinton sandstone interval in the subsurface of eastern Ohio: Northeastern Geology, v. 13, no. 2, p. 110-129.

Cox, J.C., 1980, A stratigraphic, economic and environmental analysis of the "Clinton" sandstone, southern Portage County, Ohio: unpublished M.S. thesis, Kent State University, Kent, Ohio, 112 p.

Cumberlidge, J.T. and McCullough, W.D., 1985, Economic profile of Ohio's Clinton sand: Oil and Gas Journal, v. 83, no. 19, p. 91-98, 103.

Cummings, J.W., 1931, The petroleum geology of Muskingum County: unpublished M.A. thesis, Ohio State University, Columbus, Ohio, 76 p.

Davis, T.B., 1984, Subsurface pressure profiles in gas-saturated basins, in Masters, J.A., ed., Elmworth - Case study of a deep basin gas field: AAPG Memoir 38, p. 189-203.

DeBrosse, T.A. and Vohwinkel, J.C., 1974, Oil and gas fields of Ohio: Ohio Division of Geological Survey in cooperation with Ohio Division of Oil and Gas, 1 sheet, scale 1:500,000.

Denman, R.H., 1942, The Clinton gas field of Ohio: Compass, v. 22, p. 164-170.

Drozd, R.J. and Cole, G.A., 1994, Point-Pleasant-Brassfield(!) petroleum system, Appalachian Basin, U.S.A., in Magoon, L.B. and Dow, W.G., eds., The petroleum system-from source to trap: American Association of Petroleum Geologists Memoir 60, p. 387-398.

Fenstermaker, C.D., 1969, Resume of current activity of the oil industry northeast of the Mississippi River--geographic, geologic--and magnitude of recent years' discoveries, in Rose, W.D., ed., Proceedings of the Technical Session of the Kentucky Oil and Gas Association 32nd Annual Meeting (June 6-7, 1968): Kentucky Geological Survey, Series X, Special Publication 17, p. 60-70 (?).

Frech, K.R., 1983, Aspects of diagenesis in the Clinton Formation: unpublished M.S. thesis, University of Akron, Akron, Ohio, 243 p.

Gray, J.D., 1982, Current drilling in Ohio: Oil and Gas Journal, September 20, 1982, p. 192, 197-198, 200, 205-206, 208.

________, 1982, Subsurface structure mapping in eastern Ohio: U.S. Department of Energy, DOE/ET/12131-1399, p. 3.1-3.13.

Gray, J., Lowe, C., Maslowski, A., McCullough, W., Rike, B., and Shafer, B., 1985, Clinton sandstone papers presented at the Ohio Oil and Gas Association Winter Meetings 1961 to 1978 (Abridged reprint-1985): Ohio Geological Society, Columbus, Ohio, 228 p.

Gray, J., Maslowski, A., McCullough, W. and Shafer, W.E.., 1985, The new Clinton collection 1985 (reprinted 1987 with one additional paper): Ohio Geological Society, Columbus, Ohio, 257 p.

Gurley, Jack, 1963, A productivity and economic projection method-Ohio Clinton sand gas wells: Journal of Petroleum Technology, November 1963, p. 1183-1188.

Hill, R.E., Kukal, G.C., Middlebrook, M., and Peterson, R.E., 1992, Geological, petrophysical and engineering analysis of the Clinton Sandstone–Belden & Blake Corporation Central Waste No.12 Mahoning County, Ohio: Gas Research Institute, Chicago, GRI Contract No. 5091-212-2242 to CER Corporation, 45 p.

Horvath, A.L., 1970, The Silurian of southern Ohio, in Silurian stratigraphy, central Appalachian basin: Appalachian Geological Society, Charleston, WV, p. 34-41.

Horvath, A.L., O'Brien, M.H., and Pryce, R.A., 1970, Generalized cross section, stratigraphic correlations, Silurian strata from Highland County, Ohio to Montgomery County, Virginia, in Silurian stratigraphy, central Appalachian basin: Appalachian Geological Society, Charleston, West Virginia, 1 plate.

Janssens, A., 1977, Oil and gas in Ohio--past, present, and future: 8th Annual Appalachian Petroleum Symposium (March 8-11, 1977, Morgantown, WV), p. 61-106.

Jennings, A.R., Jr.. and Darden, W.G., 1979, Gas well stimulation in the eastern United States, in 1979 SPE symposium on low-permeability reservoirs (May 20-22, 1979, Denver, CO) proceedings, paper 7914, p. 49-54.

Keltch, Brian, 1985, Depositional systems and reservoir quality of the Clinton sandstone, Guernsey County, Ohio: unpublished M.S. thesis, University of Cincinnati, 72 p.

____________, 1985, Why use geology for Clinton exploration? (examples and reasons from Guernsey County, Ohio), in Gray, J. and others, eds,, The New Clinton Collection--1985: Ohio Geological Society, Columbus, p. 19-42

Keltch, B., Wilson, D.A., and Potter, P.E., 1987, Depositional environment controls Clinton production in Guernsey County, Ohio: Oil and Gas Journal, August 24, 1987, p. 68-71.

Keltch, B.W., Wilson, D.A., and Potter, P.E., 1990, Deltaic depositional controls on Clinton sandstone reservoirs, Senecaville gas field, Guernsey County, Ohio, in Barwis, J.H., Studlick, J.R.J., and McPherson, J.G., eds., Sandstone Petroleum Reservoirs: Springer-Verlag Inc., New York, p. 263-280.

Knapp, N.F. and Stith, D.A., 1989, Characterization of trace metals in Ohio brines--final report: Ohio Division of Geological Survey Open-file Report 89-1, 15 p.

Knight, W.V., 1969, Historical and economic geology of Lower Silurian Clinton Sandstone of northeastern Ohio: American Association of Petroleum Geologists Bulletin, v. 53, no. 7, p. 1421-1452.

Knutson, C.F., 1984, Reservoir evaluation and geologic modeling for the Clinton eastern tight gas formation, phase I final report: U.S. Department of Energy Report DOE/MC/21148, 73 p.

Kornfeld, J.A., 1973, Higher gas prices boost drilling in eastern Ohio: World Oil, v. 176, no. 1, p. 57-58.

Linn, E.H., 1959, Ashtabula County shows life after long slumber: Oil and Gas Journal, v. 57, no. 2, p. 120-122.

Locke, C.D., 1967, Appalachian region oilfield reservoir investigations, Clinton sand, S.S. Fry South oilfield, Rose Township, Carroll County, Ohio: Producers Monthly, v. 31, no. 10, p. 11-13.

Lockett, J.R., 1949, Introduction to the petroleum geology of the Clinton sand in Ohio: Appalachian Geological Society Bulletin, v. 1, p. 79-93.

Lowry, R.M., Faure, G., Mullet, D.I., and Jones, L.M., 1988, Interpretation of chemical and istopic compositions of brines based on mixing and dilution, "Clinton" sandstones, eastern Ohio, USA: Applied Geochemistry, v. 3, no. 2, p. 177-184.

Maslowski, A., 1984, Deep Clinton gas sought in Ohio: AAPG Explorer, v. 5, no. 6, p. 16-17.

McCormac, M.P., Mychkovsky, G.O., Opritza, S.T., Riley, R.A., and Wolfe, M.E., in press, Play Scm: Lower Silurian Cataract/Medina Group sandstone play, in Roen, J.B. and Walker, B., eds., Atlas of major Appalachian gas plays: U.S. Department of Energy, Gas Research Institute, and Appalachian Oil and Natural Gas Research Consortium.

McMullin, D.W., 1976, Subsurface geology of the Lower Silurian Grimsby ("Clinton") sandstone of Ashtabula County, Ohio: unpublished M.S. thesis, University of Texas at Arlington, Arlington, Texas, 159 p.

Mikan, F.K., 1973, Paleoenvironmental interpretation of the lower Silurian "Clinton sands" in Guernsey County, Ohio: unpublished M.S. thesis, Ohio State University, Columbus, Ohio, 105 p.

Moore, B.J., 1982, Analyses of natural gases, 1917-1980: U.S. Bureau of Mines Information Circular 8870, 1055 p.

Motia, B.D., 1984, "Clinton" subsurface geology in parts of Summit and Portage Counties, Ohio: unpublished M.S. thesis, University of Akron, Akron, Ohio, 78 p.

Msek, S.A., 1973, Petrographic study of the Clinton Sandstone in Perry, Hocking, and Morgan Counties, Ohio: unpublished M.S. thesis, Ohio University, 56 p.

Mullet, D.J., 1983, The geology of the Albion Group of Tuscarawas County, Ohio: unpublished M.S. thesis, Wright State University, Dayton, Ohio, 104 p.

Multer, G.H., 1963, Geology of the Silurian producing zones in the Moreland oil pool, Wayne County, northeastern Ohio: Ohio Geological Survey Report of Investigations 46, 48 p., 8 plates.

Munsart, C.A., 1975, Analysis of the Lower Silurian "Clinton" sandstone in Lenox field, Ashtabula, Ohio: unpublished M.S. thesis, University of Akron, Akron, Ohio, 91 p.

Northeast Oil World, 1989, Ohio drilling diversifies: Northeast Oil World, October 1989, p. 19-23.

Oil and Gas Journal, 1993, Ohio: Oil and Gas Journal, July 19, 1993, p. 61-62.

Ortega, J.F., 1978, A regional geologic review in the subsurface of the "Clinton" sandstone in northeastern and central Ohio: unpublished M.S. thesis, Ohio University, 93 p.

Osten, M.A., 1982, The subsurface stratigraphy, paleoenvironmental interpretation and petroleum geology of the Albion Group, southeast Ohio: unpublished M.S. thesis, Kent State University, Kent, Ohio, 166 p.

Overby, W.K., Jr.. and Henniger, B.R., 1971, History, development, and geology of oil fields in Hocking and Perry Counties, Ohio: American Association of Petroleum Geologists Bulletin, v. 55, no. 2 p. 183-203.

Parsons, K.E., 1982, Regional variation in the chemistry of oil brines in the Clinton sandstone in eastern Ohio: unpublished M.S. thesis, Kent State University, Kent, Ohio, 105 p.

Parsons, K.E. and Eckstein, Y., 1982, Regional variations in chemistry of oil-brines in the Clinton Formation in eastern Ohio (abs.): Geological Society of America abstracts with programs, v. 14, no. 5, p. 267.

Pees, S.T., 1986, Geometry and petroleum geology of the Lower Silurian Whirlpool Formation, portion of northwestern Pennsylvania and northeastern Ohio: Northeastern Geology, v. 8, no. 4, p. 171-200.

Pepper, J.F., deWitt, W., Jr., and Everhart, G.M., 1953, Oil and gas geology of the "Clinton" sands of Ohio: U.S. Geological Survey Bulletin 1003-A, 15 p.

Rafalowski, J.W., 1982, The gas potential of the Lower Silurian "Clinton" sands beneath Lake Erie, U.S.A.: unpublished M.S. thesis, Ohio State University, Columbus, Ohio, 70 p.

Redic, J.G., 1970, Evaluation problems as related to Appalachian area bank financing: Journal of Petroleum Technology, October 1970, p. 1291-1298.

Russell, W.L., 1926, Oil and gas in the Clinton sand of Ohio: Economic Geology, v.21, p. 538-559.

____________, 1972, Pressure-depth relations in Appalachian region: American Association of Petroleum Geologists Bulletin, v. 56, no. 3, p. 528-536.

Sanders, L.L., 1986, Geochemistry and paleotemperatures of formation waters from the Lower Silurian "Clinton" formation, eastern Ohio: unpublished Ph.D. thesis, Kent State University, Kent, Ohio, 141 p.

____________, 1991, Geochemistry of formation waters from the Lower Silurian Clinton Formation (Albion Sandstone), eastern Ohio: American Association of Petroleum Geologists Bulletin, v. 75, no. 10, p. 1593-1608.

Schrider, L.A., Watts, R.J., and Wasson, J.A., 1969, East Canton oilfield waterflood evaluation: Society of Petroleum Engineers of AIME preprint SPE 2764, 8 p.

____________, 1970, An evaluation of the East Canton field waterflood: Journal of Petroleum Technology, November 1970, p. 1371-1378.

Seibert, J.L., 1987, Analysis of the "Clinton" sandstone and its hydrocarbon potential in south-central Mahoning County, Ohio: unpublished M.S. thesis, University of Akron, Akron, Ohio, 124 p.

Siegel, D.I., Szustakowski, R.J., and Frape, S. 1990, Regional appraisal of brine chemistry in the Albion Group sandstones (Silurian) of New York, Pennsylvania, and Ohio: Bulletin of the Association of Petroleum Geochemical Explorationists, v. 6, no. 1, p. 66-77.

Shadrach, R.S., 1989, The subsurface geology of the Clinton section (Lower Silurian, Albion Group) in Medina County, Ohio: unpublished M.S. thesis, Kent State University, Kent, Ohio, 94 p.

Shafer, W.E., 1977, Feasibility study of Ohio-Lake Erie oil and gas exploration and development: prepared for Ohio Energy and Resource Development Agency, 30 E. Broad St., Columbus, Ohio 43215, 111 p.

Singh, N., 1984, Computer analysis of the character of the Clinton sandstone and its bearing on the accumulation of oil and gas, Noble County, Ohio: unpublished M.S. thesis, Ohio State University, Columbus, Ohio, 118 p.

Slider, H.C., 1952, A study of drilling and completion methods in the Clinton sand of Perry County, Ohio: Producers Monthly, June 1952, p. 30-38.

__________, 1962, Are Clinton sand floods economically feasible?: Producers Monthly, January 1962, p. 16-19.

Smiraldo, M.S., 1985, Lithology, porosity development and silica cement source of the "Clinton" formation in eastern Ohio: unpublished M.S. thesis, University of Akron, Ohio, 132 p.

Statistics Task Group Underground Storage Committee, 1988, Survey of underground gas storage facilities in the United States and Canada 1988: American Gas Association Report, Arlington, Virginia, (Ohio part) p. 37-40.

Stith, D.A., Morth, A.H., and Hatch, J.R., 1979, Brine analysis 1972-1974: Ohio Department of Natural Resources, Division of Geological Survey Open File Report 79-1, 77 p.

Stout, Wilber, Lanborn, R.E., and Schaaf, Downs, 1932, Brines of Ohio: Ohio Geological Survey Bulletin 37, 123 p.

Susphasin, C., 1979, The subsurface geology of the Grimsby "Clinton" sandstone of Trumbull County, northeastern Ohio: unpublished M.S. thesis, Kent State University, Kent, Ohio, 59 p.

Swain, J.F., 1950, Geology and occurrence of oil in Medina sand of Blue Rock-Salt Creek pool, Ohio: American Association of Petroleum Geologists Bulletin, v.34, no.9, p.1874-1887.

Thomas, M. E., 1992, Fluid pressures in the Silurian Clinton sandstone of eastern Ohio (abs.): Geological Society of America abstracts with programs, v.24, no.3, p. 80-81.

____________, 1992, Relationship between subnormal fluid pressure and brine geochemistry in the Clinton sandstone of eastern Ohio (abs.): Geological Society of America abstracts with programs, v. 24, no. 7, p. A335.

____________, 1993, Subnormal fluid pressure in the Clinton sandstone of eastern Ohio: unpublished Ph.D. thesis, Kent State University, Kent, Ohio, 111 p.

Thompson, W.E., 1973, The concentration of selected elements in brines of Perry County, Ohio: unpublished M.S. thesis, Ohio State University, Columbus, Ohio, 59 p.

Urian, B.A., 1986, Stratigraphy and structure of Clinton sandstone interval in Wayne County, Ohio: unpublished M.S. thesis, Kent State University, Kent, Ohio, 88 p.

Walters, G.M., 1980, The subsurface stratigraphy and petroleum geology of the "Clinton" sandstone (Lower Silurian), northeast Ohio: unpublished M.S. thesis, Kent State University, Kent, Ohio, 161 p.

Watts, R.J., Schrider, L.A., and Craig, J.G., 1971, Reservoir and production characteristics of the Clinton sand, East Canton oilfield: Society of Petroleum Engineers of AIME preprint SPE 3661, 8 p.

Whieldon, C.E., Jr., 1966, Appalachian region oilfield reservoir investigations, Clinton sandstone, Carbon Hill West pool, Green Township, Hocking County, Ohio: Producers Monthly, December 1966, p. 6-7, 26.

Wieckowski, M.A., 1986, Subsurface geology of the Clinton sandstone in Coshocton County, Ohio: unpublished M.S. thesis, Kent State University, Kent, Ohio, 112 p.

Wilson, J.T., 1988, Portage County revisited--an indepth analysis of the occurrence of oil and gas in the Clinton sandstone reservoir in Portage County, Ohio: unpublished M.S. thesis, Kent State University, Kent, Ohio, 187 p.

Yates, G.E., 1991, Updated Ohio core list: Ohio Division of Geological Survey Informal Report, 19 p

Yates, G.E., Riley, R.A., Nicklaus, P.A., and Baranoski, M.T., 1990, Core-location map: Ohio Division of Geological Survey Open-file map OF-273, Scale 1:500,000.

Avary, K.L., in press, Play Sts: The Lower Silurian Tuscarora Sandstone fractured anticlinal play, in Roen, J.B. and Walker, B., eds., Atlas of major Appalachian gas plays: U.S. Department of Energy, Gas Research Institute, and Appalachian Oil and Natural Gas Research Consortium.

Berg, T.M., McInerney, M.K., Way, J.H., and MacLachlan, D.B., 1983, Stratigraphic correlation chart of Pennsylvania: Pennsylvania Topographic and Geologic Survey General Geology Report 75, 1 plate.

Boswell, R., Pool, S., Pratt, S., and Matchen, D., 1993, Appalachian basin low permeability sandstone reservoir characterizations: Report 94CC-R91-003, U.S. Department of Energy contract DE-AC21-90MC26328, Morgantown Energy Technology Center, Morgantown, West Virginia, 73 p.

Burn, T., 1993, Clinton Medina wells pay off for Atlas Resources on long term gas contracts: Northeast Oil and Gas World, October 1993, p. 9-11.

Castle, J.W., 1991, Sequence stratigraphy and depositional systems of the Lower Silurian Medina Group, Appalachian basin (abs.): American Association of Petroleum Geologists Bulletin, v. 75, no. 8, p. 1380.

Cate, A.S., 1961 ,Stratigraphic studies of the Silurian rocks of Pennsylvania, part 1, stratigraphic cross sections of Lower Devonian and Silurian rocks in western Pennsylvania and adjacent areas: Pennsylvania Topographic and Geologic Survey Special Bulletin 10, 3 p, 5 plates.

________, 1965, Stratigraphic studies of the Silurian of Pennsylvania, part 2, Subsurface maps of Silurian rocks of western Pennsylvania and adjacent areas: Pennsylvania Topographic and Geologic Survey Special Bulletin 11, 8 p., 9 plates.

Charles, J.G., Hydock, K.D., Udick, T.H., and Hall, D.R., 1982, Stimulation evaluation in the Appalachian tight gas sands: Eastern Region Meeting of the Society of Petroleum Engineers of AIME, paper SPE 11257, p. 45-47, 7 figs.

Cotter, E., 1982, Tuscarora Formation of Pennsylvania, in Guidebook for Society of Economic Paleontologists and Mineralogists Eastern Section Field Trip, 105 p.

________, 1983, Shelf, paralic, and fluvial environments and eustatic sea-level fluctuations in the origin of the Tuscarora Formation (Lower Silurian) of central Pennsylvania: Journal of Sedimentary Petrology, v. 53, no. 1, p. 25-50.

Ensign, J. 1991, Geologic observations of the Whirlpool Sandstone in western Warren County, Pennsylvania (abs,): American Association of Petroleum Geologists Bulletin, v. 75, no. 8, p. 1382.

Finley,R.J., 1984, Tuscarora Sandstone, Appalachian basin, in Geology and engineering characteristics of selected low-permeability gas sandstones: A national survey: Texas Bureau of Economic Geology Report of Investigations 138, 220 p.

Grunau, J.C., 1962, NW Pennsylvania, SW New York promise success to driller: The Oil and Gas Journal, April 2, 1962, p. 204-208.

Hamak, J.E. and Gage, B.D., 1992, Analyses of natural gases, 1991: U.S. Bureau of Mines Information Circular IC 9318, 97 p.

Hamak, J.E. and Sigler, S., 1991, Analyses of natural gases, 1986-1990: U.S. Bureau of Mines Circular IC 9301, 315 p.

Harper, J.A., 1989, Effects of recurrent tectonic patterns on the occurrence and development of oil and gas resources in western Pennsylvania: Northeastern Geology, v. 11, no. 4, p. 225-245.

Harper, J.A., Laughrey, C.D., and Lytle, W.S., 1982, Oil and gas fields of Pennsylvania: Pennsylvania Topographic and Geologic Survey Map 3, 2 sheets, scale 1:250,000.

Houseknecht, D.W., 1988, Intergranular pressure solution in four quartzose sandstones: Journal of Sedimentary Petrology, v. 58, no. 2, p. 228-246.

Jennings, A.R., Jr. and Darden, W.G., 1979, Gas well stimulation in the eastern United States, in 1979 SPE symposium on low-permeability gas reservoirs (May 20-22, 1979, Denver, CO) proceedings, paper SPE 7914, p. 49-54

Kelley, D.R., 1966, The Kastle Medina gas field, Crawford County, in Lytle, W.S., Goth, J.H., Jr., Kelley, D.R., McGlade, W.G., and Wagner, W.R., Oil and gas developments in Pennsylvania in 1965: Pennsylvania Topographic and Geologic Survey Progress Report 172, p. 30-44.

Kelley, D.R. and McGlade, W.G., 1969, Medina and Oriskany production of Lake Erie, Pierce field, Erie County, Pennsylvania: Pennsylvania Geologic Survey, 4th Series, Mineral Resource Report 60, 38 p.

Laughrey, C.D., 1984, Petrology and reservoir characteristics of the Lower Silurian Medina Group sandstones, Athens and Geneva fields, Crawford County, Pennsylvania: Pennsylvania Topographic and Geologic Survey Mineral Resource Report 85, 126 p.

Laughrey, C.D. and Baldassare, F., 1992, Isotope geochemistry of natural gases in Pennsylvania, in Harper, J.A. and Cozart, C.L., Oil and gas developments in Pennsylvania in 1990 with ten-year review and forecast: Pennsylvania Topographic and Geologic Survey Progress Report 204, p. 30, 35-36.

Laughrey, C.D. and Baldassare, F., 1995, Geochemistry and origin of some natural gases in the Plateau Province of the central Appalachian basin, Pennsylvania and Ohio (abs.): American Association of Petroleum Geologists Bulletin, v. 79, no. 9, p. 1416.

Laughrey, C.D. and Harper,J.A., 1986, Comparisons of Upper Devonian and Lower Silurian tight formations in Pennsylvania-- Geological and engineering characteristics, in Spencer, C.W. and Mast, R.F., eds., Geology of tight gas reservoirs: American Association of Petroleum Geologists Studies in Geology 24, p. 9-43.

Lutz, S.S., Zink, K.P., and Cosey, B.K., 1992, Application for Medina tight formation extension (Beaver, Butler, Lawrence Counties, Pennsylvania): Pennsylvania Oil and Gas Association report to Pennsylvania Topographic and Geologic Survey, 350+ p.

McCaslin, J.C., 1983, Rare Tuscarora wells to probe Appalachia: Oil and Gas Journal, June 27, 1983, p. 113-114.

Moore, B.J., 1982, Analyses of natural gases, 1917-1980: U.S. Bureau of Mines Information Information Circular 8870, 1055 p.

Murphy, T.B., 1984, Diagenesis and porosity reduction of the Tuscarora Sandstone, central Pennsylvania: Unpublished M.S. thesis, University of Missouri, Columbia, Missouri, 104 p.

Northeast Oil and Gas World, 1993, North Coast begins drilling in Allegheny Forest: Northeast Oil and Gas World, v. 13, no. 8, p. 6.

O'Neil, C., 1985, Characterization of northwesterly trending lineaments, French Creek, northwestern Pennsylvania: unpublished M.S. thesis, University of Pittsburgh, Pittsburgh, Pennsylvania, 53 p.

Pees, S.T., 1983, Model area describes NW Pennsylvania's Medina play (parts I and II): Oil and Gas Journal, v. 81, no. 21 and 22, p. 55-60, p.98-102

________, 1986, Geometry and petroleum geology of the Lower Silurian Whirlpool Formation, portion of NW Pennsylvania and NE Ohio: Northeastern Geology, v. 8, no. 4, p. 171-200.

________, 1987, Mapping Medina (Clinton) play by lumping clean sandstones: Oil and Gas Journal, v. 85, no. 10, p. 42-45.

________, 1989, Geological methodology illustrated via a hypothetical Medina Group horizontal well, in The 20th Annual Appalachian Basin Petroleum Symposium: West Virginia Geological and Economic Survey and West Virginia University Department of Geology and Geography, p. 50-55.

________, 1994, Silurian Medina gas revitalizing Pennsylvania's historic Oil Creek: Oil and Gas Journal, October 17, 1994, p. 116-121.

Pees, S.T. and Burgchardt, C.R., 1985, In Pennsylvania/New York---What to expect from a typical Medina gas well: World Oil, v. 200, no. 2, p. 37-40, 65.

Pennsylvania Oil and Gas Association--Gas Advocacy Committee, 1982(?), Application for recommendation that certain portions of the Medina sandstone be designated as a tight formation pursuant to the regulations of the Federal Energy Regulatory Commission (Erie, Crawford, Warren, Mercer, Venango Counties, Pennsylvania): Pennsylvania Oil and Gas Association--Gas Advocacy Committee report to Pennsylvania Topographic and Geologic Survey, 500+ p.

Petroleum Information Corporation, 1994, Atlas completes 500th well in Pennsylvania's Mercer County: Appalachian Basin Report: Petroleum Information Corporation, Denver, v. 33, no. 13, p. 1.

Piotrowski, R.G., 1981, Geology and natural gas production of the Lower Silurian Medina Group and equivalent rock units in Pennsylvania: Pennsylvania Topographic and Geologic Survey Mineral Resource Report 82, 21 p., 11 plates.

Rodgers, M.R. and Anderson, T.H., 1984, Tyrone-Mt. Union cross-strike lineament of Pennsylvania: A major Paleozoic basement fracture and uplift boundary: American Association of Petroleum Geologists Bulletin, v. 68, no. 1, p. 92-105.

Schweinfurth, S.P., deWitt, W., Jr. and Girol, V.P., 1983, Mineral resource potential of the Allegheny front and Hickory Creek Roadless areas, Warren County, Pennsylvania: U.S. Geological Survey Miscellaneous Field Studies Map MF-1442B, 14 p.

Siegel, D.I., Szustakowski, R.J., and Frape, S., 1990, Regional appraisal of brine chemistry in the Albion Group sandstones (Silurian) of New York, Pennsylvania, and Ohio: Bulletin of the Association of Petroleum Geochemical Explorationists: v. 6, no. 1, p. 66-77.

Star, I., 1983, Gas reserves in the Medina Group of northwestern Pennsylvania as related to fracture porosity and stratigraphic control: unpublished M.S. thesis, Pennsylvania State University, University Park, Pennsylvania, 100 p.

Tatlock, D.B. and Briggs, R.P., 1983, Estimates of undiscovered recoverable natural gas resources in Pennsylvania: prepared for Pennsylvania Oil and Gas Association and Pennsylvania Natural Gas Associates, 35 p., 12 plates.

Westcott, W.A., 1982, Nature of porosity in Tuscarora Sandstone (Lower Silurian) in the Appalachian basin: Oil and Gas Journal, Aug. 23, 1982, p. 159-160, 165, 167-168, 170, 173.

Yeakel, L.S., Jr., 1962, Tuscarora, Juniata, and Bald Eagle paleocurrents and paleogeography in the central Appalachians: Geological Society of America Bulletin, v. 73, p. 1515-1540.

Young, K.G., Waite, B.A., and Moody, J.L., 1991, Oil and gas well pollution abatement project: Pennsylvania Department of Environmental Resources Report ME 81495, pts. A and B, Meadville, PA, 12 p.

Zagorski, W.A.,1988, Exploration concepts and methodology for deep Medina sandstone reservoirs in northwestern Pennsylvania (abs.): AAPG Bulletin, v. 72,no. 8, p. 976.

_____________,1991, Trapping models for the Lower Silurian Medina Sandstone Group--A comparison of trapping styles and exploration methodology for both "deep" and "shallow" Medina plays in the Appalachian basin(abs.): AAPG Bulletin, v. 75, no. 8, p. 1392.

_____________, 1991, Model of local and regional hydrocarbon traps in the Lower Silurian Medina Sandstone Group, Cooperstown gas field, Crawford and Venango Counties, Pennsylvania: unpublished M.S. thesis, University of Pittsburgh, Pittsburgh, Pennsylvania, 132 p.

"CLINTON"/MEDINA BIBLIOGRAPHY (WEST VIRGINIA)

Avary, K.L., in press, Play Sts: The Lower Silurian Tuscarora Sandstone fractured anticlinal play, in Roen, J.B. and Walker, B., eds., Atlas of major Appalachian gas plays: U.S. Department of Energy, Gas Research Institute, and Appalachian Oil and Natural Gas Research Consortium.

Bambach, R.K., 1987, The Ordovician-Silurian unconformity in western Virginia and adjacent West Virginia, in Shumaker, R.C., compiler, Appalachian Basin Industrial Associates, v.13, West Virginia University, Morgantown, West Virginia, p. 2-14.

Bayles, R.E., Henry, W.H., Fettke, C.R., Harris, L.D., Flowers, R.R., and Haught, O.L., 1956, Well log, sample, and core description, in Haught, O.L., ed., Wood County deep well: West Virginia Geological and Economic Survey Report of Investigations RI-14, p. 5-28

Boswell, R., Pool, S., Pratt, S., and Matchen, D., 1993, Appalachian basin low permeability sandstone reservoir characterizations: Report 94CC-R91-003, U.S. Department of Energy contract DE-AC21-90MC26328, Morgantown Energy Technology Center, Morgantown, West Virginia, 73 p.

Bruner, K.R., 1983, Petrology and diagenesis of the Lower Silurian Tuscarora Sandstone, Kanawha County, West Virginia: unpublished M.S. thesis, West Virginia University, Morgantown, West Virginia, 148 p.

Cardwell, D.H., 1977, West Virginia gas development in Tuscarora and deeper formations: West Virginia Geological and Economic Survey Mineral Resources Series 8, 38 p.

_____________, 1982, Oriskany and Huntersville gas fields of West Virginia with deep well and structural geologic map: West Virginia Geological and Economic Survey Mineral Resources Series MRS-5A, 180 p., 1 map, scale 1:250,000.

Cardwell, D.H. and Avary, K.L., 1982, Oil and gas fields of West Virginia: West Virginia Geological and Economic Survey Series MRS-7B, 119 p.

Castle, J.W., 1991, Sequence stratigraphy and depositional systems of the Lower Silurian Medina Group, Appalachian basin (abs.): American Association of Petroleum Geologists Bulletin, v. 75, no. 8, p. 1380.

Finley, R.J., 1984, Tuscarora Sandstone, Appalachian basin, in Geology and engineering characteristics of selected low-permeability gas sandstones: A national survey: Texas Bureau of Economic Geology Report of Investigations 138, 220 p.

Folk, R.L., 1960, Petrography and origin of the Tuscarora, Rose Hill, and Keefer Formations, Lower and Middle Silurian of eastern West Virginia: Journal of Sedimentary Petrology, v. 30, no. 1, p. 1-58.

Hamak, J.E. and Sigler, S., 1991, Analyses of natural gases, 1986-1990: U.S. Bureau of Mines Information Circular IC 9301, 315 p.

Horvath, A.L., O'Brien, M.H., and Pryce, R.A., 1970, Generalized cross section, stratigraphic corelations, Silurian strata from Highland County, Ohio to Montgomery County, Virginia, in Silurian stratigraphy, central Appalachian basis: Appalachian Geological Society, Charleston, West Virginia, 1 plate.

Lukasik, D.M., 1988, Lithostratigraphy of Silurian rocks in southern Ohio and adjacent Kentucky and West Virginia: unpublished Ph.D. thesis, University of Cincinnati, 313 p.

Moore, B.J., 1982, Analyses of natural gases, 1917-1980: U.S. Bureau of Mines Information Circular 8870, 1055 p.

Patchen, D.G., 1969, A summary of Tuscarora Sandstone ("Clinton sand") and pre-Silurian test wells in West Virginia: West Virginia Geological and Economic Survey Circular 8 (reprinted with Addendum), 36 p.

Patchen, D.G., Kline, P.C., Patchen, M.A., Cardwell, D.H., and Behling, M.C., compilers, 1977, Catalog of subsurface information for West Virginia: volume 1--well samples and cores: West Virginia Geological and Economic Survey Mineral Resources Series 6-1, 189 p.

Perry, W.J., Jr., 1962, Investigations of the Brassfield-Tuscarora(Clinch) correlation problems in the Albion Series of western West Virginia and eastern Kentucky: West Virginia Academy of Science Proceedings, v. 34, p. 103-113.

Pryce, R.A., 1970, The Silurian System in western West Virginia and southeastern Ohio, in Silurian stratigraphy, central Appalachian basin: Appalachian Geological Society , Charleston, West Virginia, p. 42-46.

Smosna, R.A. and Patchen, D.G., 1978, Silurian evolution of central Appalachian basin: American Association of Petroleum Geologists Bulletin, v. 62, no. 11, p. 2308-2328.

Spencer, S., 1970, General structure and stratigraphy of the Silurian in central and southeastern West Virginia, in Silurian stratigraphy, central Appalachian basin: Appalachian Geological Society, Charleston, West Virginia, p. 47-53.

Westcott, W.A., 1882, Nature of porosity in Tuscarora Sandstone (Lower Silurian) in the Appalachian basin: Oil and Gas Journal, Aug. 23, 1982, p. 159-160, 165, 167-168, 170, 173.

Youse, A.C., 1970, A summary of Tuscarora Sandstone petroleum exploration in West Virginia, in Silurian stratigraphy, central Appalachian basin: Appalachian Geological Society, Charleston, West Virginia, p. 86-98.

APPENDIX II

Contacts with State Geological Surveys and Agencies

NEW YORK

New York State Department of Environmental Conservation, Division of Mineral Resources

1. Gregory H. Sovas, Director
2. Sandra F. Brennan, Director, Bureau of Oil and Gas Regulation
3. Donald J. Drazan, Chief, Technical Assistance Section
4. Eric B. Shyer, Mineral Resources Specialist

New York State Geological Survey

1. Robert H. Fakundiny, State Geologist and Chief
2. Richard Nyahay, Geologist

Northeastern Science Foundation Inc.

1. Jon Bass, Geologist

OHIO

Ohio Division of Geological Survey

1. Thomas M. Berg, State Geologist and Chief
2. Lawrence H. Wickstrom, Geologist
3. Garry E. Yates, Environmental Technology Supervisor

Ohio Division of Oil and Gas

1. Michael P. McCormac, Geologist

PENNSYLVANIA

Pennsylvania Topographic and Geologic Survey

1. Donald M. Hoskins, Director and State Geologist
2. Cheryl Cozart, Data Management Specialist
3. John A. Harper, Chief, Oil and Gas Section
4. Christopher D. Laughrey, Oil and Gas Geologist

WEST VIRGINIA

West Virginia Geological and Economic Survey

1. Larry D. Woodfork, Director and State Geologist
2. Douglas G. Patchen, Program Manager, Appalachian Oil and Natural Gas Research Consortium
3. K. Lee Avary, Geologist

APPENDIX III

Project members and their contribution(s)

Kerry L. Aggen - GIS support for land use/land cover map.

Robert D. Hettinger - Cross section B-B'; Lower Silurian stratigraphy and facies; sequence stratigraphic interpretations.

Ben E. Law - Interpretation of reservoir pressure and temperature data.

John J. Miller - Location and availability of seismic profiles.

Vito F. Nuccio - Burial, thermal, and petroleum generation history models.

William J. Perry, Jr. - Cross section C-C'; Lower Silurian stratigraphy and facies.

Stephen E. Prensky - Application of log suites to fracture detection.

Robert T. Ryder - Chief, Appalachian basin project; cross section A-A'; Lower Silurian stratigraphy and facies; Clinton/ Medina/Tuscarora oil and gas map; bibliography.

John R. SanFilipo - Structure contour map; application of digital contouring programs.

Craig J. Wandrey - Storage and manipulation of digital data; GIS technology; land use/land cover cell map; gas production data base; formation water quality data; environmental impact of continuous-type gas accumulations