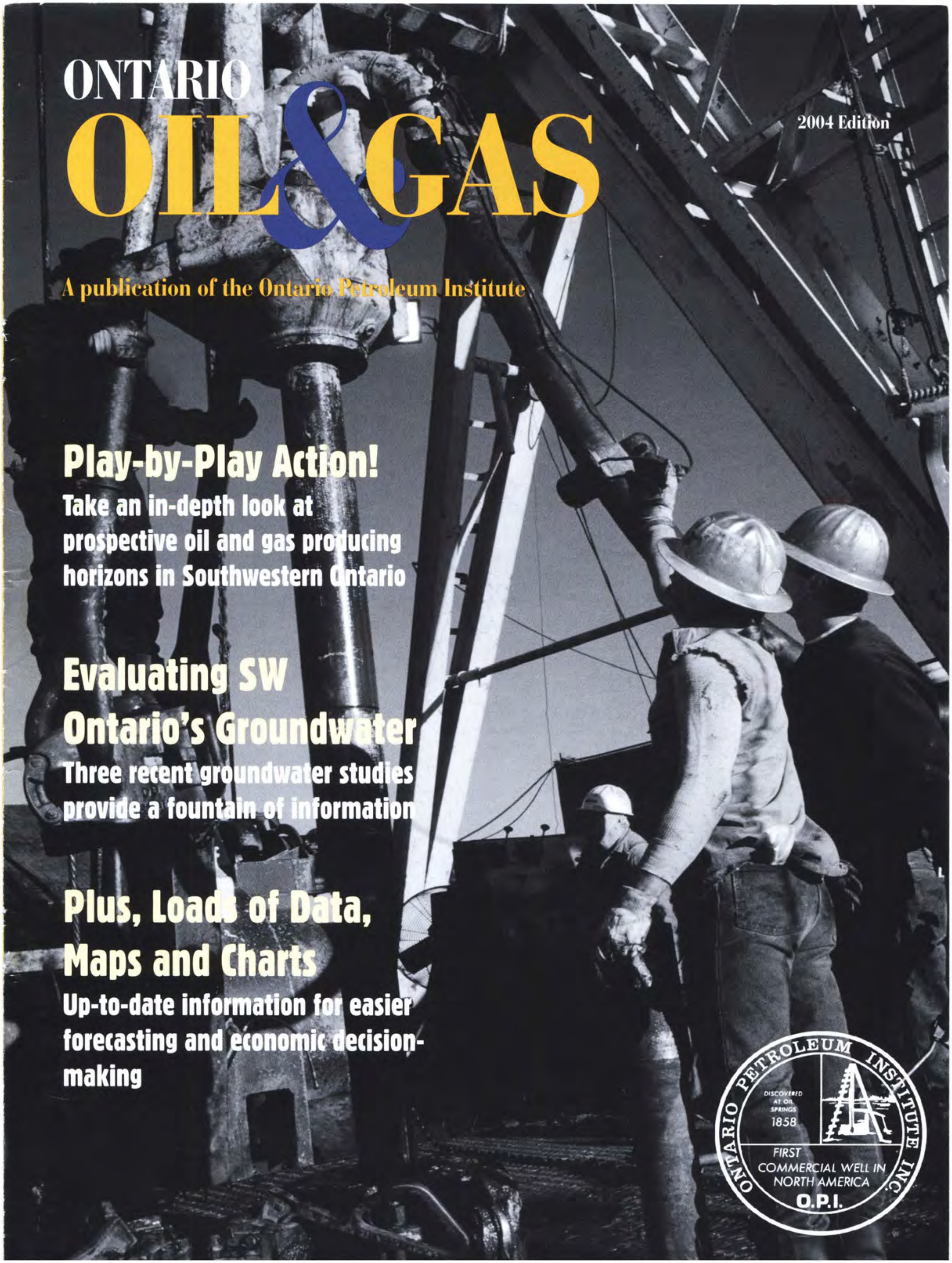

ONTARIO OIL & GAS

2004 Edition

A publication of the Ontario Petroleum Institute

Play-by-Play Action!

Take an in-depth look at prospective oil and gas producing horizons in Southwestern Ontario

Evaluating SW Ontario's Groundwater

Three recent groundwater studies provide a fountain of information

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Up-to-date information for easier forecasting and economic decision-making

ONTARIO PETROLEUM INSTITUTE INC.
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FIRST COMMERCIAL WELL IN NORTH AMERICA
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ONTARIO OIL & GAS

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2004 Edition

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WELCOME

AS THE NEW Minister of Natural Resources, it is a pleasure for me to convey my best wishes through the pages of *Ontario Oil & Gas* Magazine. The magazine provides a valuable asset for industry to stay abreast of oil and gas opportunities and issues here in Ontario.

I know how important the province's natural resources are for Ontario's economy and for the people who depend on them for a living. I am looking forward to working with the oil and gas industry to ensure that those resources are managed in a sustainable manner.

The oil and gas industry has contributed greatly to the province's prosperity over the last 145 years. While drilling and production activity has been continuous for almost a century and a half, the province still has a lot more to offer. Last year, 82 new oil and gas wells were drilled in Ontario resulting in 18 discovery wells. In addition, oil production was 214,000 cubic metres and gas production reached 420 million cubic metres.

The Ministry of Natural Resources will continue to develop its partnership with the industry to ensure that the benefits from this resource are ongoing. The ministry is pleased to work closely with the industry through the Ontario Petroleum Institute.

I wish the readers of *Ontario Oil & Gas* Magazine, and all those in the industry, a successful year.

Hon. David Ramsay
Minister of Natural Resources

OPI REPORT

WELCOME TO THE SECOND EDITION of the *Ontario Oil & Gas* annual magazine.

As the new Executive Director of the Ontario Petroleum Institute (OPI), I would like to acknowledge the work of the previous Executive Director, Steve Fletcher, and the many article contributors who have helped put together this issue. When I announced to my colleagues that I was moving to London to work at the OPI, I was able to show them last year's excellent issue that described the active, viable industry we have in this province. This year's issue promises to continue that tradition.

Mel McDonough explores a piece of the history of drilling in Ontario in his article, "Drilling in 1896." While our industry is rich with such history, equally important is the fact that the size of the industry and the level of technology have grown creating a thriving environment. We look to the future in the five-part article, "Play by Play Action." These five articles focus on prospective oil and gas producing zones in Southwestern Ontario.

The Ontario Oil and Gas industry continues to enjoy a positive relationship with the Ontario Government through the Ministry of Natural Resources (MNR). We have a unique partnership with the MNR, through the Oil, Gas and Salt Resources Trust (for which I have the pleasure of being Managing Director). This partnership is helping to ensure that technological growth happens not only in the field, but also in research so that timely and relevant data can be used by those involved in the Ontario oil and gas industry. Andrew Hewitt's article, "The Give and Take of Information," explores this relationship.

As you read *Ontario Oil & Gas*, I hope that you will gain an even stronger appreciation for the opportunities that can be found in Ontario and with the Ontario Petroleum Institute.

Sincerely,

Joe Van Overberghe
Executive Director
Ontario Petroleum Institute

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Play-by-Play Action!

A five-part look at prospective oil and gas producing horizons in Southwestern Ontario

By Joe Van Overberghe
Ontario Petroleum Institute

STANDING AT BAT and considering where you should hit that next pitch? You study the playing field, and then you pick your spot. And if you're right? Bang! You can hit it out of the park!

In this series of five articles, we aim to help you do just that when deciding where to drill that next prospect. First, you need to understand a bit about the field on which you are playing. It never hurts to know how the game was played here in the past and where the new opportunities may lie. The next series of articles document the past, present and, perhaps most importantly, the future production plays in Southwestern Ontario.

Thank you to the contributors of these fine articles for sharing their unique knowledge of the opportunities in Ontario.

PLAY BALL!

Middle Devonian Reservoirs of Southwestern Ontario

By Duncan Hamilton
Greentree Gas & Oil Ltd.

THE MIDDLE DEVONIAN LUCAS and Dundee formations of Ontario have produced about 44 million barrels of oil (MMBO), which equates to approximately 54% of Ontario's oil production to date. The first oil discovered in North America was from the shallow Middle Devonian carbonates at Oil Springs, Ontario in 1858. Today, 145 years later, some of these early discoveries are still producing.

Three of the largest oil fields in Ontario are Middle Devonian in age and include Petrolia (18 MMBO), Rodney (10.4 MMBO) and Oil Springs (10 MMBO). Bothwell-Thamesville (3.3 MMBO) and Glencoe (1.1 MMBO) were also very significant discoveries. The Middle Devonian reservoirs, therefore, historically have been economically a very important hydrocarbon play in Ontario.

Early exploration methods included drilling surface seeps, the use of dowsers, psychics, and rudimentary geological mapping. A number of modern techniques that have been successfully employed recently include computer mapping, the use of gravity and magnetics, 2D seismic, and geophysical logs. The use of modern engineering applications, such as cased-through completions, well stimulations, horizontal drilling and secondary recovery, have significantly improved daily production volumes and ultimate recoverable reserves.

Middle Devonian oil production is confined to two distinct reservoir units in the Lucas formation and three types of reservoirs in the Dundee Formation. Most known Middle Devonian reservoirs are structurally controlled by the localized preservation of thick sections of underlying Silurian Salina salts.

From an economic prospective, the Middle Devonian reservoirs continue to be a very attractive geological target due to their shallow depth (400 to 500 feet, or 120 to150 metres), high-gravity oil (38 API), relatively high yields (8,000 to 10,000 barrels/acre) and long, productive life-spans. Prospective regions in Ontario have been only lightly explored and the potential exists for new significant discoveries.

History of the Play and Production

The first oil in North America was discovered at Oil Springs in 1858 from Middle Devonian carbonates. A number of other shallow Middle Devonian pools were found in the late 1800s and include Petrolia (1862), Bothwell-Thamesville (1862) and Wallacetown (1898). The 1900s saw three significant discoveries: Glencoe (1917); Watford-Kerwood (1938); and the Rodney Pool in 1949 (Table 1). Of these significant early discoveries, four are still on production today.

The past 10 years have seen the drilling of only 24 wells directed to Middle Devonian targets and have resulted in the discovery of one new oil pool and one potential natural gas pool. In 1999, Greentree Gas & Oil Ltd. discovered the Aldborough 7-D-VII pool, which is a separate structure on trend of the Rodney pool (Figure 1). The 7-D-VII pool currently has four producing wells of which one is a horizontal completion. In 2000, Rubicon et al #7 Harwich 18-IV was reported to be a new pool Middle Devonian natural gas discovery.

Middle Devonian reservoirs have produced 44 MMBO out of a total of 82 MMBO produced in Ontario to the end of 2002. Devonian oil production in 2002 amounted to132,649 barrels, or approximately 10% of the total production for the year as compared to 41.3% of Ontario's production in 1983. The decline in volumetric importance of Middle Devonian reservoirs is primarily due to industry focus on the Ordovician Trenton-Black River reservoirs and a low-level of activity directed to Devonian targets.

General Geology

Oil production in the Middle Devonian sediments is confined to the Lucas Formation and overlying Dundee Formation. Within the predominantly carbonate sequence a number of reservoir types have been identified. The Lucas Formation hosts two distinct reservoir types: a microcrystalline dolomite unit and calcareous sandstone. The dolomite unit is the primary reservoir in the Oil Springs pool and has porosity in the range of 12% to 30% and permeability of five to 430 mD. The sandstone unit is the producing reservoir in the Glencoe pool, where porosity ranges from 10% to 21% and permeability generally varies from 50 to 200 mD.

The Dundee Formation hosts one very significant unit known as the "Columbus zone," but production has also been derived from fractured limestones and fractured limestones with a microporous matrix. The

POOL NAME	DISCOVERY YEAR	CUMULATIVE PRODUCTION [barrels]	ACTIVE
Oil Springs	1858	10,027,000	Yes
Petrolia	1862	18,132,000	Yes
Bothwell-Thamesville	1862	3,314,000	Yes
Wallacetown	1898	252,000	No
Glencoe	1917	1,152,000	No
Watford-Kerwood	1938	130,000	No
Rodney	1949	10,401,000	Yes

Table 1: Major Middle Devonian oil pools of Ontario [cumulative production current to 2002 incl.].

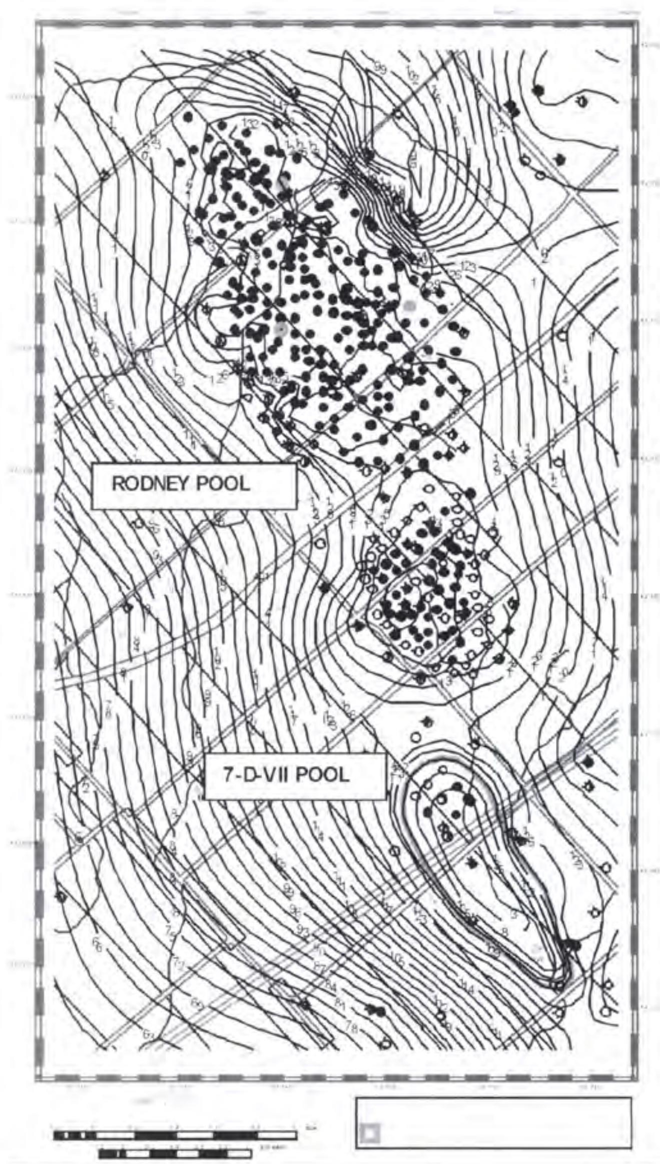
Columbus zone is a siliclastic-rich dolomitized limestone with porosity commonly in the 12% to 30% range and permeability varying between 50 and 2500 mD. The Columbus zone is the producing reservoir in the Rodney pool.

Reservoir Example

The Rodney pool provides one of the best illustrations of a Middle Devonian pool in Ontario due to the relatively recent timing of development and availability of accurate geological and engineering data. The Rodney pool and a separate Middle Devonian structure located to the south of the Rodney pool, known as the Aldborough 7-D-VII pool, are situated to the east of a large fault structure that trends northeast-southwest (Figure 1). The fault was instrumental in providing the mechanism for dissolving up to 60 metres of Silurian Salina salt to the west of the fault in post Middle Devonian time. Approximately 50 to 55 metres of Salina salt is preserved underlying the Rodney and 7-D-VII pools to the east of the fault. The salt remnant provided the structure and resulting trap for the overlying Middle Devonian pools. Both pools have between 10 and 15 metres of structural closure.

The Rodney and 7-D-VII pools are also good examples where the use of modern exploration and engineering methodology have led to increased production, recoverable reserves and a new discovery. Rodney is presently undergoing secondary recovery through water-injection. The pool was placed on water-injection between 1962 and 1964 and resulted in a 232% increase in daily production volumes and to date approximately 55% recovery of the estimated original oil in place. After 53 years of production, Rodney is still producing approximately 120 BOPD with a decline rate of less than 5%.

The 7-D-VII pool was initially defined using a combination of computer geological mapping,



gravity, magnetics, and petrophysical analysis. Two-dimensional seismic was acquired over the potential feature, and an anticlinal structure on the top of the Dundee formation with closure was imaged and was a good fit with the other data sets. Subsequent successful drilling results confirmed the existence of the structure. Cased-through completions, stimulations and horizontal drilling were successfully employed in the initial development stages of the pool. Due to the shallow depth of the pool, reservoir pressure is very low and a form of secondary pressure injection will be implemented to maximize daily production volumes and ultimate recoverable reserves.

SUMMARY

Middle Devonian pools remain some of the largest oil producing reservoirs in Southwestern Ontario, although the Ordovician Trenton-Black River reservoirs are becoming increasingly more economically important. Exploration activity and success directed to Middle Devonian targets has been very sporadic and poor in the past 50 years, but there remain opportunities for new discoveries utilizing modern exploration tools and engineering methods. Computer mapping and the use of gravity and magnetics has proven valuable in defining fault structures and potential preserved sections of Silurian Salina salt. 2D and 3D seismics are valuable tools to more accurately image the potential structures for drilling and development. Modern engineering methods, such as cased-through completions, stimulations, horizontal drilling and secondary recovery, have led to substantial increases in daily production volumes and ultimate recoverable reserves.

Reservoirs and Production from the Silurian Carbonate Rocks

By R.O. Cochrane
Cairnlins Resources Limited

ROCKS OF MIDDLE and Upper Silurian age in Southwestern Ontario are predominantly carbonates and evaporites with minor interbeds of shale. The hydrocarbon reservoirs in this unit are found in reef buildups and in structural traps associated with porous bands in carbonate units. The depth of the reservoir varies from 275 to 780 metres. Natural gas is the predominant hydrocarbon. In the 148 fields, 70 are gas producers, 46 produce both oil and gas, and 32 are oil pools. Most of the hydrocarbon production from Silurian carbonates originates in Kent and Lambton Counties and in Lake Erie. Smaller contributions come from Elgin, Middlesex, Essex and Huron counties.

FORMATION DESCRIPTION

The productive formations of the Silurian carbonates are the Salina A-2 Unit, Salina A-1 Unit and the Guelph. The Guelph, of Upper Middle Silurian age, is a light brown dolostone of variable thickness; the equivalent formation is called the Niagaran in Michigan. Three kinds of reefs have developed within the Guelph, as shown on Exhibit 1. Reef mounds occur in a belt around the edges of the Michigan Basin. In Southwestern Ontario, this belt runs through Bruce, Huron, and Lambton counties and the top part of Kent County. Reef buildups in excess of 50 metres are called pinnacle reefs, whereas reefs with buildups less than 50 metres are called incipient or subdued reefs. Bailey (2002) has called the thicker incipient reefs "half reefs" and suggests a different history of growth for these reefs. Platform or patch reefs flank the Michigan Basin and run through Essex, Kent, Elgin counties and beneath the western and central parts of Lake Erie.

The Salina A-1 Unit consists of a lower member of anhydrite that is overlain by lime muds that are dark grey to black at the base becoming lighter in colour at the top of the unit. In many localities, the top five to 10 metres of the A-1 were deposited in a shallow tidal flat and have beds of light to medium brown dolomite interspersed with anhydrite. These beds have secondary porosity that is often locally enhanced by the presence of a fault.

The SalinaA-2 Unit consists of a basal anhydrite member overlain by a bed of clean crystalline halite with a thickness ranging from zero to 30 metres. Above the halite is a medium-grey shaly carbonate with a thin, universally present, shale bed, often called the A-2 Shale Marker. Above the A-2 Shale, the unit grades from a lime mud at the base upward, to light to medium brown sucrosic dolomite interspersed with anhydrite beds at the top. The thickness of the dolomite unit varies from three to 10 metres. The A-2 Unit is overlain by halite of the Salina B Salt, and, as a result, the porosity in the dolomite at the top of the A-2 Unit is usually plugged with halite and anhydrite. However, when the overlying salt has been entirely removed by dissolution, the porosity at the top of the A-2 Carbonate can become effective as a trap for natural gas.

TRAP & SEAL

Stratigraphic traps in the Silurian carbonates are of two types: reefs and porous lenses controlled by facies variations. The primary porosity in the reef mounds is enhanced by dolomitization and episodal karsting during and following reef development, and, as a result, permeability in the reefs can be exceptional. High deliverability in pinnacle reefs makes them ideal reservoirs for storage of natural gas. Unfortunately, this porosity is often infilled by halite, anhydrite and carbonate cements during diagenesis and burial. The incipient reefs and platform reefs are usually sealed by the overlying anhydrites and impermeable limestones of the A-1 Unit. Pinnacle reefs are sealed by encapsulating anhydrite and impermeable carbonates of the A-2 Unit and, in the case of tall mud mounds in Huron and Bruce Counties, by the anhydrites of the Salina B Unit.

Two fields have facies-controlled traps at the top of the Salina A-1 Carbonate. Dolostone lenses in a tidal flat facies are present in the top 10 metres of the A-1, and contain natural gas. The seal is the anhydrite bed of the A-2 Unit.

Structural traps can be found on the up-thrown side of faults where the porous zones in the A-1 Carbonate are lifted above regional levels. Where dissolution of the B-salt occurs near the fault zone, gas may also be trapped in the upper section of the A-2 Carbonate. If the fault was active during the deposition of the A-1 Carbonate, porosity is enhanced at a significant distance from the fault trace. The Becher West and Zone pools are examples of this phenomenon.

A group of fields in Aldborough and Dunwich townships in Elgin County produce natural gas and minor crude oil from the A-1 Unit and to a lesser extent from the A-2 Unit. The trap is controlled in part by the facies variations at the top of the A-1 Unit and also in part by structure. The structure is anticlinal and is related to draping over the Guelph reef, gentle regional folding, or both.

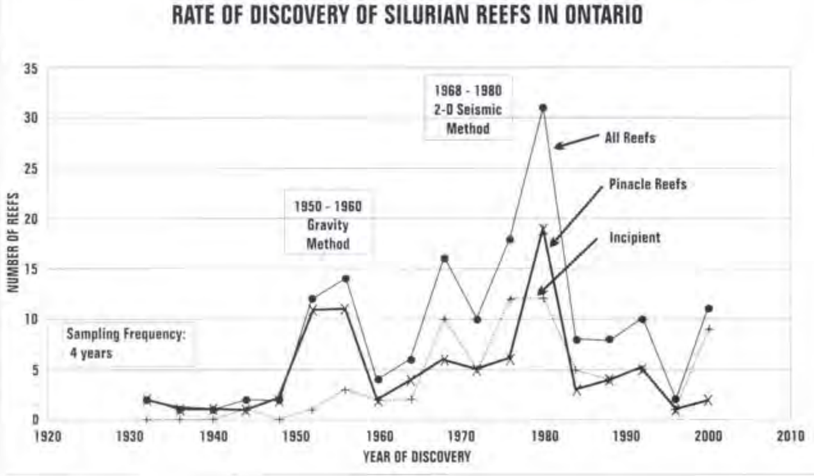
The third type of structural trap is a result of dissolution of salt. The B-Salt is commonly removed by solution usually along or associated with a fracture. The leaching of the salt within the top of the A-2 carbonate opens up porosity that traps natural gas. Three accumulations of this type have been discovered in Kent County. The most significant of these is the Morpeth Field which covers an area of 1,549 acres and has produced 163.9-million m3 (5.8 bcf) of gas.

HISTORICAL PRODUCTION

The first gas production from the Silurian Carbonates was recorded in 1889 with the discovery of the Kingsville Leamington Field in Essex County. The discovery of Tilbury Pool, the largest gas pool in Ontario, occurred in 1906. Deepening of the Oil Springs shallow Devonian reservoir led to the discovery of the Oil Springs incipient reef in 1913, and the first pinnacle reef was the Dawn 59-85 Pool, which was found in 1931.

Table 1 shows a summary of the exploration history for Silurian Carbonates to the end of 2002, with cumulative production as of the end of 1999. A total of 217 pools have been discovered with a cumulative production of 20 billion m3 (709 bcf) of gas and 2.13 million m3 (13.4 million) barrels of oil. The largest gas production originates in the platform reefs, with the most significant contribution coming from one field, the Tilbury Pool, with 7.73 billion m3 (274 bcf). The Glasgow-Talbot Fields in Lake Erie, which are commingled as the Morpeth Production Unit, have provided significant historical gas production (cumulative 1.78 million m3, 63.2 bcf) and are still on production. Pinnacle reefs rank second in cumulative production; the 52 reefs collectively have produced 5.61 million m3 (199 bcf) and 1.26 million

RATE OF DISCOVERY OF SILURIAN REEFS IN ONTARIO



m3 (7.92 million bbl) of oil.

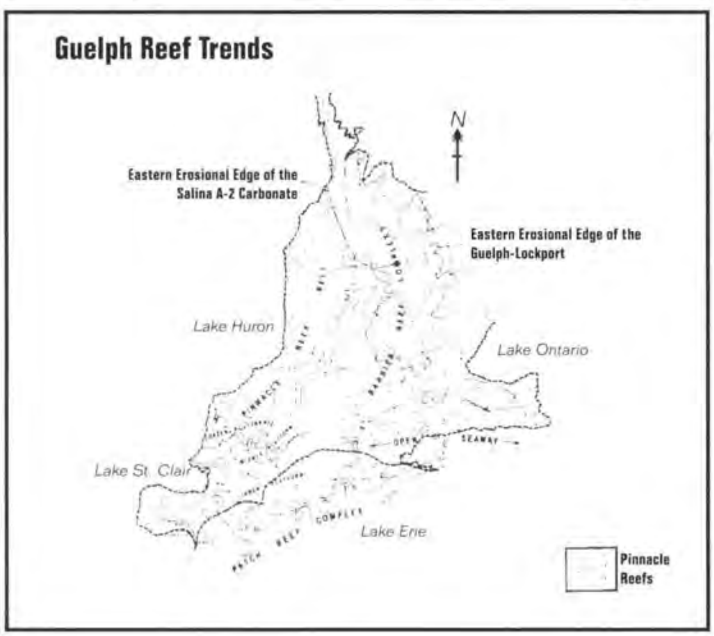
Depleted pinnacle reefs are usually converted to natural gas storage if their reservoirs have high permeability and deliverability, and if they are located near the compressor stations in Dawn and Moore townships of Lambton County. To date, 28 depleted pinnacle reefs and one incipient have been converted into the storage of natural gas.

SELECTED FIELD EXAMPLES

A good selection of examples of Silurian Carbonate fields can be found in published articles by Koepke & Sanford (1965) and by Bailey and Cochrane (1990).

The Tilbury Pool, a large platform reef, extends over 19,600 acres in Raleigh Township of Kent County and another 18,200 acres offshore in Lake Erie. To the end of 1999, the cumulative production is 7,730 million m3 (274 bcf). The Fletcher Field, discovered in 1905 on the north end of the Tilbury Pool, produced 192,000 m3 (1.21 million barrels) of oil before abandonment.

The Kimball Colinville Pool, discovered in 1947 in Moore Township of Lambton County, is the largest of the pinnacle reefs, with a cumulative production to the end of 1999 of 970 million m3 (34.4 bcf) of gas, with minor quantities of oil. The Corunna-Seckerton reef complex, discovered in 1950 in Moore Township, produced less gas, [384 million m3 (13.7 bcf)] than Kimball Colinville, but had significant oil (501,000 m3, 3.14 million barrels).



The most prolific structural pool was the Zone Field in Kent County. It was discovered in 1943, has produced 300 million m3 (10.7 bcf) of gas and lies on the upthrown side of the Electric Fault. On the upthrown side of the same fault is the Chatham Field in Kent County. Discovered in 1936, this pool has produced 203 million m3 of gas. The most significant oil production from a structural trap in the A-1 Unit was discovered in 1946 at the Becher West Pool in Sombra Township of Lambton County. The field was successfully waterflooded and has a cumulative production of 417,000 m3 (2.62 million barrels) of oil and 186 million m3 (6.59 bcf) of natural gas.

Production and reserves from incipient reefs are significantly less than those from pinnacle reefs because of their smaller area and thinner pay sections. The largest of this type, the Otter Creek reef complex in Sombra Township, was discovered in 1968 and has produced 55 million m3 (1.97 bcf) of gas.

EXPLORATION METHODS

The rate of discovery of pinnacle reefs reflects the progress of technology. A gravity anomaly is present over the large pinnacle reefs because the halite beds in the Salina Formation are locally thinner over the reef crests. As a result, gravity surveys were the most successful method for the detection of reefs and other structural features associated with the dissolution of salt. As shown on Exhibit 2, the peak in the discovery rate between the years 1948 and 1956 is the result of an active drilling program and gravity exploration. Exploration by seismic methods commenced in 1968, and the peak in the discovery rate for reefs between the years 1968 and 1980 is due to the success of this method. Since 1999, three-dimensional seismic has been useful in delineating known reef reservoirs for development of natural gas storage. Use of three-dimensional seismic for exploration has been concentrated in the townships of Dawn, Enniskillen, Moore and Sombra of Lambton County and the southern part of Huron County. The technique has yielded an increase in the number of incipient reefs but disappointingly very few new pinnacle reefs.

Horizontal wells have been used for the exploitation of existing reef reservoirs at the Sombra Pool and Corunna-Seckerton Pool. Successful development of the Black Creek Pool in Sombra Township by horizontal wells was documented by Druet et al 2002. The combined use of three-dimensional seismic and horizontal drilling to locate untapped gas reserves at the Mandaumin North reef in Plympton Township of Lambton County in 2001 was unsuccessful.

Current Exploration & Development

At the present time, exploration for Silurian reservoirs is at low ebb. In 2002, a total of eight exploratory wells and 13 development wells were drilled into Silurian Carbonates. Two of the exploratory tests were completed for natural gas production. The Sombra 7-A-XI Pool in Sombra Township of Lambton County is the most recent pinnacle reef and was found in the year 2000.

Talisman Energy Inc has an ongoing program to exploit the platform reefs in Lake Erie. In 2002, nine development wells were drilled in the Glasgow-Talbot Reef and the Silver Creek Reef; five of these wells were completed for gas production.
Two secondary oil recovery projects in pinnacle reefs have been initiated since 2001. The Plympton 5-19-VI Pool and the Wanstead Pool are currently being waterflooded.

Markets & Commodity Prices

Crude oil is trucked from wellsites all over Southern Ontario to the storage facility in Sarnia operated by Marcus Terminals Inc. From this facility, oil is sold in batches to the immediately adjacent Imperial Oil Limited refinery.

A network of natural gas pipelines is accessible throughout Southwestern Ontario. The operator of a well is responsible for the construction of a pipeline to the gas transmission line, the leasing of a meter site, and the purchase of the metering equipment. Gas can be sold directly to the pipeline operator or can be transported through the pipeline to a third party upon payment of negotiated transmission charge.

Future Potential Development

The search for Silurian Carbonate reservoirs is in a mature stage. No longer can operators blanket an area with seismic and expect to make reef discoveries that will pay out the exploration costs and still provide an acceptable return on investment. In the past five years, expensive 3-D seismic technology has found very few pinnacle reefs in the heavily-explored four townships (Dawn, Enniskillen, Moore and Sombra) in Lambton County. The reprocessing of existing seismic control, the acquisition of prospect-specific 2-D seismic, and geological studies of existing wells are cost-effective methods to search for reefs in this area.

Exploration effort to locate reefs outside the four

Tabulation of Hydrocarbon Traps in Silurian Carbonates of Southwestern Ontario

Trap Type	Gas Pools	Oil and Gas Pools	Oil Pools	Barren Traps	TOTAL POOLS	Gas Storage Pools	Cumulative Production to end 1999 Metric Units Gas million m3	Metric Units Oil 1,000m3	Imperial Units Gas bcf	Imperial Units Oil 1,000 bcf	Examples
A] Stratographic Traps											
A.1] Reefs											
A.1a] Platform Reefs	13	4	5	6	28	0	12,456	206	442	1,294	Tilbury, Fletcher Morpeth and Silver Creek Units
Includes 5 production units in Lake Erie											
Pinnacle Reefs	31	14	7	34	86	28	5,613	1,259	199	7,920	Kimball-Colinville, Dawn 156, Bickford, Corunna, Seckerton, Grand Bend, Warwick
Incipient Reefs	16	15	17	27	75	1	302	120	11	757	Otter Creek, Betch East, Dawn 28-II, Sombra 4-16-IX, Cromar
SUBTOTAL	60	33	29	67	189	29	18,371	1,585	652	9,971	
A.2] Facies Control	1	1	0	0	2	0	19	0	1	2	Moore 50-50-Front, Camden Gore 6-10-IX
TOTAL STRATOGRAPHIC	61	34	29	67	191	29	18,390	1,585	653	9,973	
B] Structural Traps											
B-1] Fault-related Traps	6	6	1	1	14	***	1,158	534	41	3,356	Zone, Chatham Brigden, Camden Gore, Becher West
B-2] Anticlinal Traps	1	5	2	1	9	0	237	6	8	39	Townline, Mosald
B-3] Salt Dissolution	2	1	0	0	3	0	181	0	6	2	Morpeth
TOTAL STRUCTURAL	9	12	3	2	26	0	1,576	540	55	3,397	
TOTAL	70	46	32	69	217	29	19,966	2,125	708	13,370	

townships is warranted. Although many of the known reefs in the other townships of Lambton County and in Bruce and Huron counties are unproductive because of absence of permeability, halite plugging, and subnormal pressures, commercial quantities of hydrocarbons have been discovered in a number of reefs, such as Grand Bend, Plympton 5-19-VI, Sarnia 2-11-VIII, Warwick, and Chatham D Pools. A large reef, Stephen 4-11-XXII, was discovered in 1999 in Stephen Township of Huron County. A combination of seismic exploration with surface geochemical surveys is a way to reduce risk in this play. One of the problems with the search for reefs in Bruce and Huron counties was the absence of a market for natural gas. However, the opportunity to convert natural gas to electricity is now available, and the rising price of electricity will soon make this process a viable option.

One of the side benefits of seismic exploration is the location of fault structures. Structural traps in the A-1 and A-2 Units are associated with faulting. As a result, a re-assessment of existing seismic control could provide prospects for exploration in the Salina A-1 and A-2 Units. In addition, horizontal drilling techniques should be effective in draining this type of reservoir more efficiently.

Lower Silurian Sandstone Reservoirs

By M. Molgat
Talisman Energy Inc.

Gas bearing sandstones of the Lower Silurian Whirlpool, Grimsby and Thorold formations create one of the most significant gas plays in the Appalachian Basin. The play spans a large area of 700 km in length by 200 km in width extending from northeastern Kentucky, into Ohio, Lake Erie, Southwestern Ontario, northwestern Pennsylvania and to western New York (Figure 1). These sandstones have been, and continue to be, economically important gas reservoirs in Southwestern Ontario. In the past decade, they have accounted for about 46% of total Ontario gas production, producing more than 2.3 billion cubic metres (82.5 Bcf) of gas. The bulk of current production comes from offshore Lake Erie fields. Smaller contributions come from fields in Norfolk and Haldimand counties. Trapping mechanisms are primarily stratigraphic and diagenetic. Gas

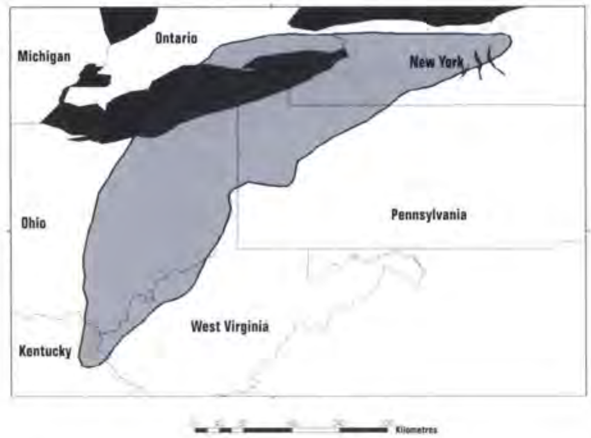


Figure 1. Geographical extent of the Lower Silurian gas play in the Appalachian Basin. Modified from McCormac et al., 1996.

productivity appears to be related to porosity and permeability variations caused by clay content, diagenetic histories, and, on a basin-wide scale, burial depths. Depths of productive reservoirs in Ontario range from 60 metres in Niagara County to 625 metres in central Lake Erie.

Historical Production

Gas in the Whirlpool, Grimsby and Thorold sandstones was first discovered in 1889 in Welland Township in relatively shallow and permeable reservoirs that could be produced without stimulation. Its discovery and proximity to market provided the momentum that led to further drilling activities. By 1910, all the large onshore pools in Niagara, Haldimand, Norfolk, and Brant counties had been discovered. Despite having over a century of production history, the development and extension of these pools continues to this day. Cumulative gas production from onshore pools to the end of 1994 was 6.4 E^9m^3 (227 Bcf).

The Silurian sandstone play was pursued into Lake Erie in the early 1960s, at which time rotary drilling, hydraulic fracturing and electric well logging had become readily available. Between 1959 and 1970, all the known large Lake Erie sweet gas pools were discovered. Drilling activities, number of operating companies, number of drilling rigs, and production, peaked in the mid 1980s. Today, only one operator is actively pursuing Silurian gas in Lake Erie. Cumulative gas production from the offshore pools to the end of 1994 was 4.4 E^9m^3 (156 Bcf).

Formation Description

Siliciclastic reservoirs of Early Silurian age comprise the Whirlpool and Grimsby formations of the Cataract Group (Medina Group in New York State) and the Thorold Formation of the Clinton Group.

The Whirlpool Formation disconformably overlies red marine siltstones and shales of the Upper Ordovician Queenston Formation and is conformably overlain either by argillaceous, fossiliferous dolomites of the Manitoulin Formation (central Lake Erie) or marine shales of the Cabot Head Formation (east Lake Erie; Niagara and Haldimand/Norfolk counties). The Whirlpool comprises two main units: a fluvial unit and an estuarine to transitional marine unit (Zagorski, 1991; Cheel and Middleton, 1993; Cheel *et al.*, 1994; Johnson, 1998). The fluvial unit is typically white to gray in color and is dominantly composed of unfossiliferous, very fine- to fine-grained, cross-stratified quartzose sandstone. The estuarine to transitional marine unit is also composed of very fine- to fine-grained quartzose sandstones, but is typically overlain or interstratified with shale and exhibits varying degrees of bioturbation (Johnson, 1998). Whirlpool thickness is irregular and, locally, can be up to nine metres thick. It has an average thickness of about four to five metres and thins and pinches out to the north and northwest where it becomes transitional with dolomites of the Manitoulin Formation (Figure 2A).

The Grimsby Formation, which is also referred to as the Clinton sandstone as a result of miscorrelations that took place during the early development of the play, overlies fully marine shales of the Cabot Head Formation. In Ontario, the contact between the Cabot Head and Grimsby formations is delineated by a ravinement surface characterized by channel cuts and associated lag deposits (Benincasa, 1996).

The Grimsby can be subdivided into two units. The lower unit is composed of fine- to medium-grained, medium- to large-scale, cross-stratified, quartzose sandstones with common mud couplets. Sandstones are commonly white in color. This lower unit is interpreted to have been deposited in subtidal channel complexes (Benincasa *et al.*, 1997). The upper unit is composed of very fine- to fine-grained, small-scale cross-stratified, quartzose sandstone interstratified with bioturbated shale partings/beds. Sandstones in this unit commonly are red in color and are interpreted to represent discrete tidal channels and associated mud flats (Benincasa *et al.*, 1997). It is important to note that color in the Grimsby is controlled by variations in the oxidation state of iron-rich sediment and relative abundance of organic matter within the sediments (Duke *et al.*,

Figure 2. Subcrop edges of the Whirlpool (A), Grimsby (B), and Thorold (C) formations. Modified from Cochrane and Bailey (1986).

1991). As such, changes in color are diagenetic in origin and do not correspond to unit boundaries. Thickest Grimsby sections in Ontario are up to 20 meters thick and are located near the international border in east and central Lake Erie. The Grimsby generally thins to the west and north, where it passes laterally into shales of the Cabot Head Formation (Figure 2B).

The Thorold Formation, also known as the "Stray Clinton," overlies the Grimsby Formation and, in turn, is overlain by shaly dolomites and dolomites of the Reynales and Irondequoit formations. The Thorold is generally composed of fine-grained sediment and is also typically more highly bioturbated than the Grimsby Formation. Lithologically, it is composed of very fine quartzose sandstone with shale interbeds and contains abundant accessory minerals (Fisher, 1954; Benincasa, 1996). The Thorold has been interpreted to represent the basal transgressive deposits of the Reynales-Irondequoit succession (Clinton Group), and composed of reworked Grimsby deposits (Sanford, 1969). It reaches a maximum thickness of six meters and is mainly distributed in Haldimand/Norfolk counties and in parts of east and central Lake Erie (Figure 2C).

Reservoir Characteristics

Lower Silurian reservoir characteristics are highly variable. Pay thickness is generally thin, ranging from 0.5 to less than 10 cumulative metres. Pay is commonly both vertically and laterally discontinuous. Sandstone porosity values range from 2% to 18%. However, producing wells generally have values greater than 8% and are generally non-economic below this. Similarly, permeability varies greatly, ranging from 0.1 to 100 millidarcies and better reservoirs typically have values over five millidarcies. Water saturations also vary significantly from pool to pool, ranging from 15% to more than 85%. Gas-water contacts, where present, are observed at different structural levels, which reflects the laterally discontinuous nature of these reservoirs. Initial flow rates are also highly variable as they are dependant on reservoir characteristics and completion techniques. Wells produce anywhere from a few hundred to several tens of thousands cubic metres of gas per day (several tens to a few million cubic feet per day). First year declines range from 40% to 60%, second year is about 25%, and long-term decline is in the order of 8%. Cumulative production ranges from approximately 1.5 million cubic metres to almost 100 million cubic metres (~0.05 Bcf to >3 Bcf).

There appears to be little correlation between depositional facies, net sand, and production. Commercial gas production is largely controlled by porosity and permeability variations within the reservoir, which in turn are controlled by three main factors: grain size, clay content, and degree and type of cementing (Overbey and Henniger, 1971). The principle reason for low porosity and permeability values in many wells, is the almost complete occlusion of primary intergranular porosity by authigenic silica and carbonate cements. Silica cementation is pervasive in the Cataract Group, whereas carbonate cementation is secondary in importance, although locally significant.

Reservoirs that have a cumulative production greater than 8.5 million cubic metres (>0.3 Bcf) generally have well-developed secondary intergranular porosity related to partial dissolution of primary calcite cement and, to a lesser extent, corrosion of silica cement and selective dissolution of feldspars. In Ohio and Pennsylvania, high-porosity trends tend to be linear and align with major surface lineaments that are interpreted to be expressions of reactivated deep-seated fractures and fault zones (Zagorski, 1991). In this example, the presence of natural fractures allowed for a large volume of fluids to circulate locally through the strata, partially dissolving feldspar grains and calcite cement, creating enhanced secondary porosity. Relationships between structure and production have also been observed locally in Ontario. For example, some Whirlpool reservoirs in Lake Erie appear to be linear, and this linearity can be loosely correlated to deep-seated structures.

In Ontario, Lower Silurian reservoirs contain sweet gas and are generally devoid of oil. The natural gas is primarily composed of methane (82.5% methane, 7% ethane, 2% propane) with an average specific gravity of 0.66. Its average heating value is 40.4 megajoule/m^3 (1084.3 BTU/ft3). Whirlpool, Grimsby and Thorold gas production is commonly commingled. It should be noted that regulators in Ontario require offshore wells to be plugged back from the zones with oil shows, or be abandoned if oil cannot be plugged off.

Exploration Methods

Most of the large onshore and offshore gas pools were discovered simply by continued drilling activities. New discoveries led to follow-up development in surrounding and adjacent areas until individual pools and fields were delineated. Seismic information did not assist with exploration and development until the 1960s. Seismic data is of little use to delineate shallow channels or determine abundance of sandstone in most parts of Southwestern Ontario because of poor data quality, but it has been used to delineate structural highs interpreted to be potential traps. However, this method of exploration has resulted only in mediocre success to date.

Almost all Ontario wells that target the sandstones are vertical wells. Only three attempts were made at drilling horizontal wells in the sandstones in Lake Erie, with no noticeable improvements in productivity.

Current Exploration & Development

A major rejuvenation of interest and drilling activities for onshore Lower Silurian gas appeared at the turn of the new millennium as high natural gas prices made this low-volume, tight sandstone play more economically feasible. In 2001, a total of 48 wells tested Lower Silurian strata, 44 of which were reported as gas or potential gas producers. In 2002, activities dropped slightly and a total of 41 wells were drilled for gas in Silurian sandstones, 39 of which were reported as gas or potential gas producers. The bulk of the 2002-2003 onshore activities took place in Bayham, Houghton, and Walsingham areas, but there were also 13 wells drilled and completed as private gas wells in parts of the Lincoln, Welland and Haldimand gas fields.

Drilling activities for sweet gas in Silurian sandstones in Lake Erie had been in a lull since 1999 as the preferred target over the past few years has been Guelph reservoirs. However, interest in the

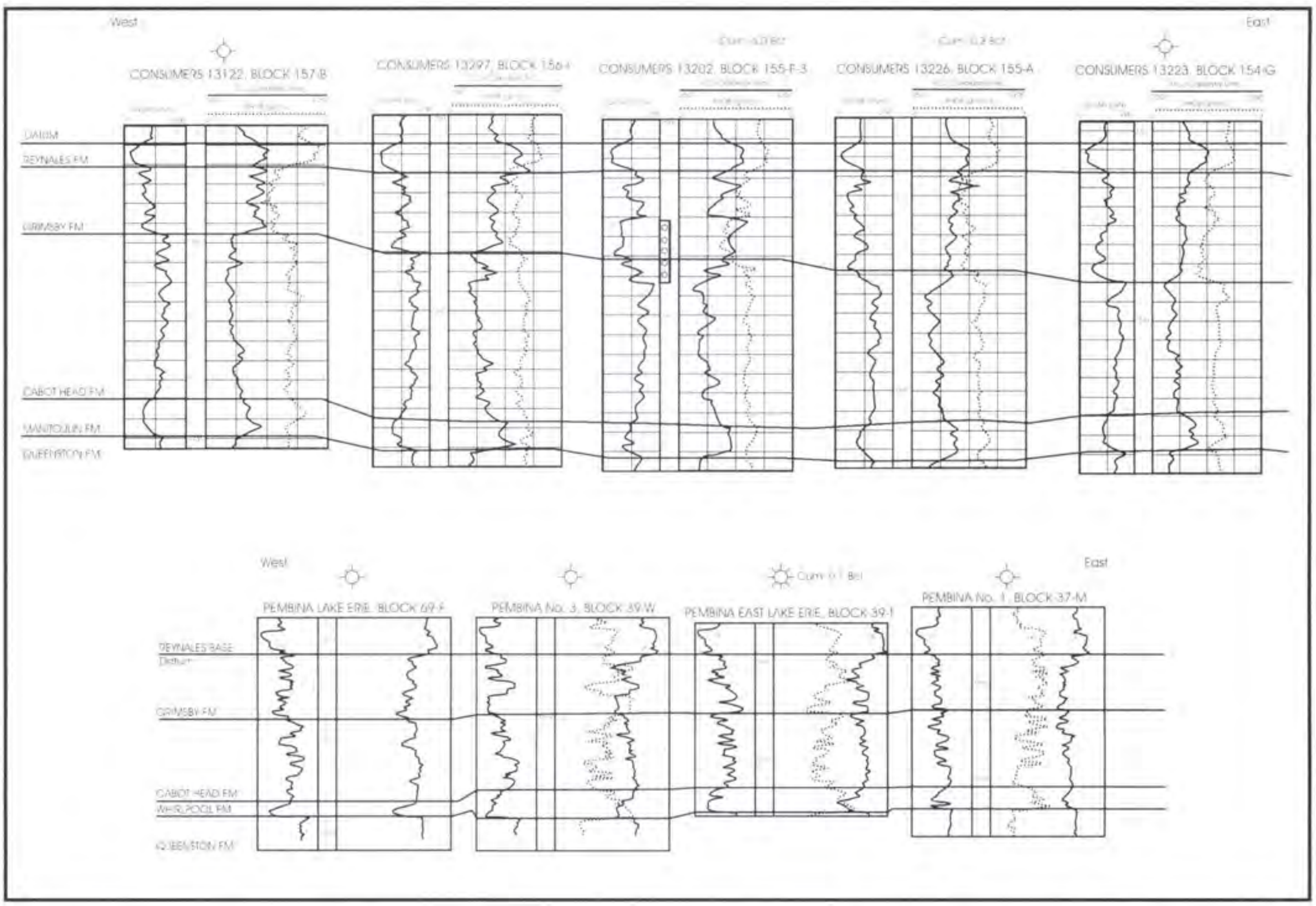


Figure 3. Geophysical log responses and cross-sections of the Cataract Group in central and east Lake Erie, Ontario. The Grimsby and Thorold formations are the main gas producers in central Lake Erie [A]. The Whirlpool and Grimsby formations produce in east Lake Erie [B]. Modified from Benincasa [1996] and Johnson [1998].

Silurian sandstone gas play has increased in 2003, and 10 wells were licensed with Grimsby and/or Whirlpool reservoirs being primary targets.

Future Potential Development

Probable gas reserves identified for the Whirlpool, Grimsby, and Thorold formations in Ontario were estimated at 760 Bcf at the end of 1981 (Cochrane and Bailey, 1986). The offshore portion accounted for about 96% of total probable reserves, while onshore areas accounted for just over 3% (mostly in Norfolk and Haldimand townships). Onshore gas exploration is deemed to be limited due to extensive drilling of pools over the past century, high recovery factors of greater than 95%, and close spacing between wells (10 to 40 hectares or 25 to 100 acres) (Cochrane and Bailey, 1986). Conversely, offshore spacing is more typically 255 hectares (640 acres), recovery factors are estimated at 15% and many tracts have not been drilled or properly evaluated. The best area for future exploration and development activities is considered therefore to be offshore, in central and east Lake Erie. Gas reserves in U.S. Lake Erie remain undeveloped due to a moratorium on oil and gas-related activities.

Middle Ordovician Trenton-Black River Group Carbonate Play

By Ian Colquhoun
Veteran Resources Inc.

The Lower Paleozoic rocks located beneath Essex and Kent counties within Southwestern Ontario have been a focus of exploration for oil and gas over the past few decades. These structurally controlled oil fields are interpreted to have formed within a regional fracture network that provided conduits for fluids that dolomitized the regional limestone creating the reservoirs. A later pulse of hydrothermal fluid assisted with hydrocarbon maturation, migration and emplacement. The resulting linear fields have dimensions that range from 300 to 600 metres wide and several kilometres long (up to 10 km) — such as the case in Ontario — to several orders of magnitude larger, as observed in the Albion-Scipio and Stoney Point oil fields within central Michigan. Fractured-related dolomite and fractured limestone reservoirs within Middle Ordovician carbonates in the Appalachian Basin have been described for recent oil and gas discoveries within New York, Ohio, Pennsylvania and West Virginia.

The narrow reservoirs that developed are recognized on seismic sections as a sag or structural low, which coincides with those areas of the reservoir that are well fractured, dolomitized and contain reservoir quality rock. These structures have been interpreted as graben-like features created by bounding faults. However, an alternative explanation includes regional fault and fracture patterns with accompanying shears created by wrench-faulting during several phases of extensional tectonics in latter phases of the Taconic and Alleghanian orogenies. The dominant NW-SE trends are attributed to wrench faulting associated with the Pennsylvanian Appalachian orogeny, overprinting the major Paleozoic fault and fracture patterns within southeastern Michigan and Southwestern Ontario.

Reservoir development within the Trenton-Black River carbonates is attributed to dolomitized grainstones that contain high matrix porosities, surrounded by fractured and dolomitized mudstones, wackestones and packstones. Intensity of fracturing combined with a high degree of dolomitization of bioclastic facies within the Sherman Fall Formation provided linear-oriented and continuous reservoirs (e.g., Mersea Township,

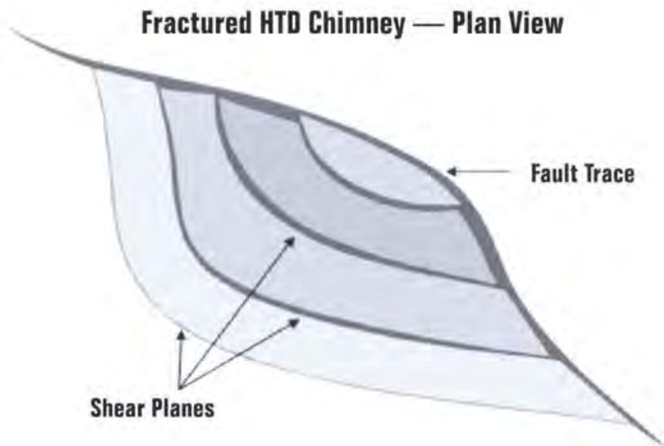


Figure 1: Plan view of isolated dolomite chimney structure showing main fault trace, shear planes and normal faulted and rotated blocks that define the feature recognized on seismic.

Essex County). These reservoirs were created by pervasive dolomitization with laterally extensive secondary porosity along a trend of dolomite chimneys. Dolomite chimneys were created by hydrothermal dolomitization within negative flower structures and localized by en-echelon shearing along a main fault trace (Figure 1). Less intense fracturing and dolomitization within relatively bioclastic-poor sediments provided isolated dolomite chimneys or pod-like reservoir development (e.g., Dover Pool, Dover Twp, Kent Co).

For a regional comparison, clean grainstone units and well-developed matrix porosity characterize the best hydrocarbon-bearing structures in Southwestern Ontario, whereas fractured mudstones and wackestones with accompanying vugular porosity characterizes reservoir development of Albion-Scipio and Stoney Point fields in southeastern Michigan.

HISTORICAL PRODUCTION

Ordovician dolomites of the Trenton and Black River groups of the Michigan Basin have been prolific oil and gas producers since the late 1800s with the discovery of gas in the Trenton Group carbonates east of Findlay, Ohio and oil outside of Lima, Ohio in 1894 and 1895 respectively. The field that developed following these discoveries produced more than 500,000 bbl of oil and approximately 1 Tcf of gas during the late 1800s and into the early 1900s (Caprarotta et al. 1988). Bownocker (1903) documented the first oil and gas discoveries that started on the northern flanks of the Findlay-Kankakee Arch in Indiana and Ohio in 1884. Oil production since then exceeds 500 million barrels from linear highly dolomitized reservoirs around the Bowling Green fault zone (Keith 1985).

The first linear fracture-related, hydrocarbon bearing Trenton-Black River pool in Ontario was discovered at Dover in 1917 (refer to pools map insert). The Dover field is also an elongated, east-west trending, dolomitized reservoir located within a synclinal sag structure (Burgess 1960). The Dover pool has produced approximately 13.5 Bcf of gas and 250,000 bbl of oil. The first commercially produced Trenton oilfield was discovered in 1936 from the Deerfield oil pool located in Monroe County, Dundee Township, in the state of Michigan. This oilfield is located along the Lucas-Monroe monocline that is an extension of the Bowling Green fault zone.

In 1954, the Northville field was the next Trenton oilfield to be discovered. This reservoir was unique in that it produced oil and gas from Dundee (Devonian), the Salina-Niagarian (Silurian) and Trenton-Black River rocks (Ordovician). The Trenton-Black River production came from dolomitized and fractured limestones located on the east flank of the Northville fault structure (Landes 1970). It was this discovery of linear, fault/fractured, structurally bound and dolomitized units that led to the discovery of the Albion-Scipio field in 1957. During the 1950s and 1960s a number of new discoveries in Ontario occurred, including Colchester, Malden and Kingsville. These small pools also appeared to be fracture related. The Colchester oil field produced from the Cobourg and Sherman Fall formations, which formed a porous bioclastic limestone succession. Since then, significant discoveries include Dover 7-5-VE (1982), Hillman (1983), Stoney Point (1983), Wheatley (1985) and Renwick (1987) oil pools. All of these fields are linear features that have fracture-related reservoir development (refer to pools map insert). In Michigan, the Stoney Point oil pool was discovered just 8 km east of the Albion Scipio pool, located primarily on the basis of soil-gas geochemistry.

In Southwestern Ontario, the largest Ordovician oilfield is Goldsmith (>3 million barrels recovered) and the largest gas field is Dover (>13.5 Bcf recovered). The Ordovician play area is approximately 120,000 km^2 with an estimated 100 million barrels of oil in place. Only 20 million barrels have been recovered, leaving at least 20 to 40 million barrels recoverable. The estimates on gas production are more speculative, but are estimated at 33 Bcf in place with 29 Bcf recovered. Total number of wells drilled for Ordovician oil and gas targets in Southwestern Ontario are estimated at about 1,700.

TRAP AND SEAL

Hydrocarbons produced from Ordovician oilfields may have originated within the Middle Ordovician shales and migrated at depth along fractures into the Cobourg and Sherman Fall formations (Sanford 1961). Hydrocarbons were thought to be trapped stratigraphically on the flanks of a synclinal structure within dolomitized rocks bounded by limestones of the Cobourg and argillaceous and bioclastic limestones of the Sherman Fall Formation. Alternatively, the hydrocarbons may have originated from within the Ordovician carbonates themselves since they contain sufficient organic carbon content (up to 3 weight percent) to be their own source rock. The Ordovician dolomites contain thermally mature organic matter and have been exposed to high enough temperatures to generate their own hydrocarbons (Colquhoun 1991). Trapping mechanisms include the overlying Middle Ordovician shales (approximately 200 metres thick), a thin cap dolostone atop the Cobourg (1 to 5 metres thick), regional and tight limestones along the lateral edges of the reservoirs, and hydrothermal dolomite textures provide local permeability barriers between shear planes and individual dolomite chimneys.

Sanford (1961) suggested exploration for oil within the Trenton Group carbonates that exhibited thinner (<120 m) and cleaner (i.e. without a high argillaceous content) lateral facies changes extending to the north and south of the central part of the Michigan Basin. He further suggested that many stratigraphic and sedimentologic traps exist within areas of Essex and Kent counties because the Findlay Arch passes through both counties. He postulated that higher degrees of deformation have taken place in these areas producing tectonically inclined reservoirs.

Seismic data throughout Essex and Kent counties suggests that negative flower structures created these traps, but are not, in most cases, responsible for hydrocarbon traps within overlying Silurian and Devonian carbonates. Negative flower structures are not unique to Essex and Kent counties since they have been identified on seismic in Lambton County, but display different timing and function not directly associated with hydrocarbon trapping features.

Subsequent producing wells along existing trends have been discovered through recognition of the linear trend of the reservoir, the sag at the top of the Trenton above producing wells observed on seismic, and the adopted NW-SE trending line from known producers. Explorationists working in Michigan and Southwestern Ontario referred to the synclinal sag structure as the "Golden Gulch."

Rock Formation Description

The Middle Ordovician (Caradocian) limestones of Southwestern Ontario have been interpreted on the basis of outcrop studies (refer to stratigraphic section insert). It was proposed that these sediments were generated during the development of the Appalachian foreland basin (Brett and Brookfield 1984). The depositional sequences represent deepening-upward cycles of shallow marine sedimentation. Glacio-eustatic sea-level changes are postulated to have controlled some aspects of carbonate sedimentation onto the Ordovician shelf (Brett and Brookfield 1984). The sediments are described as a series of crinoidal limestone and marlstone belts extending out from the shallow basin edge, whereby the facies patterns are the result of a storm-dominated, shallow crinoidal ramp (Kobluk and Brookfield 1982). The shallow crinoidal ramp of amalgamated grainstones adjacent to the shoreline grades seaward into the subtidal slope that is dominated by interbedded wackestones and mudstones (Kobluk and Brookfield 1982).

In the crinoidal ramp model, the highest energy conditions are close to shore along the bank, and the lower energy conditions occur offshore as the seafloor gradually deepens (c.f. Aigner 1985 as presented in Colquhoun 1991, 2001). The resulting facies pattern is a series of belts from massive crinoidal limestones at basin edge to marlstones within the basin centre. Lime muds with interbedded grainy beds and continuously changing facies characterize the offshore environments. Potential modern analogues for these Ordovician environments are the Arabian shelf of the Persian Gulf and the Sahul shelf of northern Australia (Brett and Brookfield 1984).

The muddy sediments occur on the distal ramp or basinal depositional setting. The crinoid content decreases further offshore where the brachiopod wackestones, mudstones and marlstones predominate. The cleaner, graded skeletal wackestones are deposited as storm layers or tempestites (Aigner 1985) on muddy bioturbated distal ramp sediments. These sediments formed as coarse-grained fossil debris fell out of suspension followed by fine calcisiltite material after each storm. The beds are encased in bioturbated mudstones that are commonly deposited on the distal portion of the ramp. The ramp dynamics and resulting facies patterns can be observed in several cores within the workshop, with excellent examples of amalgamated grainstones from the proximal portion of the ramp to the interbedded wackestones and mudstones of the distal environments. Similar facies patterns have been described in the Trenton outcrop from Peterborough to Lake Simcoe, Ontario (Kobluk and Brookfield 1982).

Relatively minor fluctuations in sea level provided wide lateral depositional facies shifts over Southwestern Ontario. Depo-centres during Trenton-time are interpreted to the southeast in the Allegheny Basin and to the northwest in the Michigan Basin, therefore carbonates deposited on

SW-NE Transect through NW-SE Trend

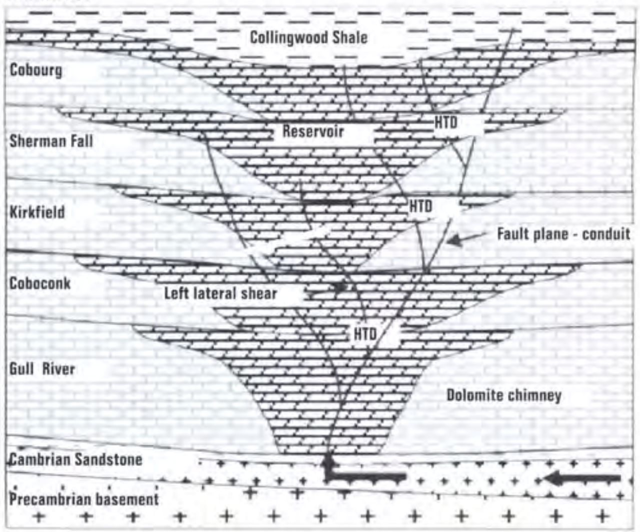


Figure 2a: Cross-section through the northwest-to-southeast oriented reservoirs in Mersea Twp.

N-S Transect through W-E Trend

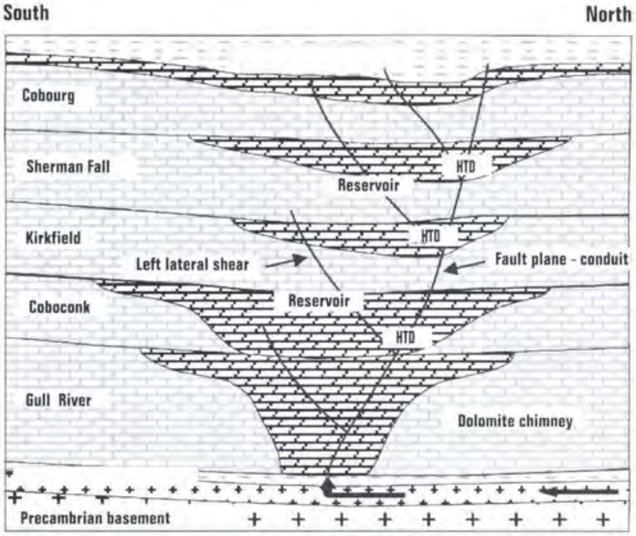


Figure 2b: Cross-section through the west-to-east oriented reservoirs encountered in Dover Twp.

the ramp are replaced by muds as water depths and distance from the area of primary carbonate production increase.

The main reservoir rock within the Ordovician Trenton-Black River carbonates is the Sherman Fall Bioclastic (Fragmental) member of the Trenton Group, an oil-bearing unit over much of Essex and Kent counties and a significant gas-bearing unit within Dover Township, Kent County (i.e. Dover Pool). A second oil-bearing reservoir is the Coboconk Formation within the Black River Group within both Rochester and Dover townships of Southwestern Ontario.

The lithologies that make up these reservoirs within both Sherman Fall and Coboconk formations include bioclastic units containing abundant type 2 and 3 facies with less muddy rock types, described as facies types 4a,b, c and 5 (c.f. Aigner 1985 as described in Colquhoun 1991, 2001). The Trenton and Black River Group carbonates vary in thickness from 120 to 150 metres up to a total thickness of approximately 300 metres throughout oil producing areas within Southwestern Ontario. Diachronous sedimentation patterns resulted from an active arch system that began during the Middle Ordovician, which affected carbonate facies distribution within the Cobourg and Sherman Fall formations of the Trenton Group. Reservoir development is best developed within uppermost bioclastic rocks of the Sherman Fall Formation (Trenton Group) that varies in thickness from 10 to 15 metres in southern Essex and Kent counties, and the Coboconk Formation (Black River Group) is fairly uniform in thickness (approximately 30 metres).

Reservoir Characteristics

The reservoir was created by an early pulse of warm waters predating maturation, migration and emplacement of hydrocarbons as suggested by extensive geochemical analyses of reservoir and hydrothermal dolomite types and produced fluids (c.f. Colquhoun 1991). Core analyses demonstrate wide ranges in matrix porosity from 3% to 15% with accompanying vugular and fracture porosity, which can range from 18% to greater than 45% for large, open fractures. Permeability estimates range between tens and several hundred millidarcies within specific portions of the reservoir, and as high as 10 Darcies when large, open fractures are encountered, which greatly enhances initial productivity rates. Homogeneous reservoir quality grainstones exhibit average porosities of 8% with an average permeability of 150 millidarcies. Hydrothermal fluids were responsible for maturation of organic material, the migration and emplacement of the hydrocarbons (c.f. Colquhoun 1991) and the creation of hydrothermal karst or solution-enhanced porosity zones with porosities that vary between 30% and >45% on density logs. Well productivity is variable depending upon the number of open fractures encountered by the well bore, which increases local permeability.

Typical water saturation within normal hydrodynamic regimes for Trenton-Black River reservoirs vary between 15% and 40%, irreducible water saturation commonly ranges between 15% and 25%. These reservoirs also contain prolific water production zones located much higher within the stratigraphic column, sometimes accompanied by small to large quantities of oil depending on well location within the structure. These discrete zones contain remnants of the hydrothermal karst waters responsible for creation of a wide variety of reservoir destructive mineral phases and features.

Two distinct types of Ordovician reservoirs exist within Southwestern Ontario. The first has a prominent NW-SE trend, and the second has a prominent W-E trend (Figure 2a, b). The main characteristics of the NW-SE trend include more pervasive dolomitization throughout both the Trenton and Black River group carbonates, an oil reservoir in the Sherman Fall bioclastic (fragmental), and linear or continuous reservoir connecting several chimneys. The main characteristics of the W-E trend include pervasive dolomitization in the Black River Group carbonates with local dolomite in the Sherman Fall bioclastic (Trenton), dual reservoir potential with gas in the Sherman Fall bioclastic and oil in the Coboconk formation, and a pod-like reservoir where dolomite chimneys are commonly isolated.

Exploration Methods

Surface reconnaissance methods that are good indicators of physicochemical processes related to hydrocarbon oxidation from near-surface hydrocarbon migration include organic and inorganic soil gas geochemistry, magneto-telluric, and airborne multi-spectral and photographic surveys. Airborne magnetic surveys show a modest correlation of magnetic highs located along either side of these linear features. These surveys allow a first-order investigation into unknown parts of a basin for chemical and structural leads related to hydrocarbon traps within the subsurface but cannot approximate the depth at which to find them.

Traditional exploration methods include 2-D seismic used to identify the structural low or sag feature atop the Trenton. In recent years, operators began using more robust seismic methods, such as Mega Bin 3-D seismic surveys or 2-D swaths, which simulates a 3-D survey, but for less cost. The 3-D seismic survey allows the operator to more easily identify the dolomite chimney characteristics within the hydrothermal dolomite play.

Current Exploration and Development

Drilling in the Ordovician play by Consumers' Gas, Pembina Exploration, Ram Petroleum and Paragon Petroleum Corporation (and its predecessors) during the 1980s and '90s boasted up to 67% success for exploration wells and more than 80% for development wells. Their successor, Talisman Energy, posted development success numbers above 90%.

Future exploration areas

Assessing new areas for future exploration and development for Ordovician oil and gas requires detailed mapping of the bioclastic facies within the Sherman Fall and Coboconk formations on a regional scale. This will be reliant upon the availability of subsurface data, well logs and samples to evaluate the facies relationships on a sequence stratigraphic framework in order to determine the presence, orientation and continuity of bioclastic rocks and to predict reservoir style. Since the reservoir is structurally controlled, it is necessary to determine the orientation and intensity of fracturing and faulting within an area in order to predict reservoir orientation. It is also necessary to determine the timing of faulting and fracturing in relation to reservoir formation to assess if the reservoir has remained intact or if it has been breached. The most important task is the ability to evaluate the presence or absence of fluids that create a reservoir, the hydrothermal fluids necessary for hydrocarbon maturation, migration and emplacement, and suitable conduit(s) in the form of underlying Cambrian sands. All these criteria are important to determine if reservoir creation and hydrocarbon migration was possible within a new play area.

Cambrian Reservoirs of Southwestern Ontario

By Michael Dorland
Ontario Oil, Gas & Salt Resources Library

UPPER CAMBRIAN SILICICLASTIC and carbonate rocks are the oldest preserved Paleozoic strata in Southwestern Ontario and lie directly on the Precambrian basement. They underlie approximately 48,000 km^2 (Bailey and Cochrane, 1984), an area slightly less than 50% of that underlain by Paleozoic strata. The regional Precambrian basement structure of Southwestern Ontario is dominated by a broad, northeast-trending high known as the Algonquin Arch. It is an extension of the Findlay Arch to the southwest, separated by a structural depression known as the Chatham Sag. The Algonquin and Findlay Arches separate the Appalachian Basin from the Michigan Basin (Figure 1).

During Upper Cambrian time, sediments were deposited throughout Southwestern Ontario, onlapping and extending over the Algonquin Arch as early Paleozoic seas transgressed the Precambrian surface (Johnson et al., 1992). Subsequent exposure and erosion during development of the regional pre-Middle Ordovician Knox unconformity resulted in the removal of Lower Ordovician and much of the Cambrian strata from Southwestern Ontario (Johnson et al., 1992). The distribution of Cambrian strata around the edges of the Algonquin arch with successively younger units overlapping one another to lie directly on the Precambrian basement indicates that the arch had a configuration very similar to the present during Upper Cambrian time (Sanford and Quillian,1959).

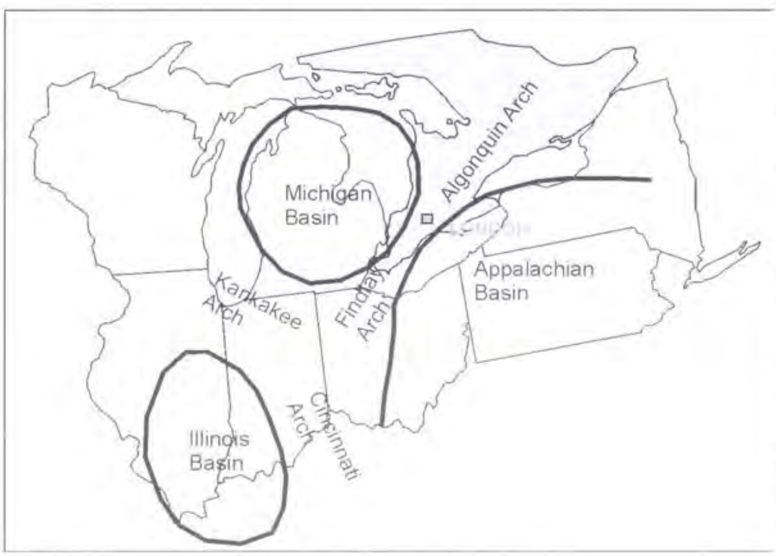


Figure 1. Regional structural setting of southern Ontario (shaded area), showing position of major arches and basins.

Hydrocarbon reservoirs (Figure 2) are found in stratigraphic traps along the Cambrian subcrop edge and in structural traps associated with faulting. The depth of the reservoir varies from 700 to 1,200 metres. All commercial oil and gas pools discovered to date are on the Appalachian Basin side of the Algonquin Arch. On the Michigan Basin side, where the Cambrian lies virtually untested, no commercial accumulations have been found.

Formation Description

Thickness of the Cambrian section ranges from approximately 175 metres in the centre of Lake Erie to 0 metres at the pinch-out edge. In the western part of Southwestern Ontario (west of about longitude 81°, or approximately London, Ontario) the basal rocks consist of mainly quartz sandstone (Mount Simon Formation) overlain by sandstone, sandy and shaly dolomite (Eau Claire Formation) and then buff to grey-buff dolomite (Trempealeau Formation). In the eastern part (east of about longitude 81°), the basal rocks consist of arkose and quartz sandstone (Potsdam Formation) overlain by dolomite, sandy dolomite and sandstone (Theresa Formation), and then light buff, crystalline dolomite (Little Falls Formation). As the Cambrian strata approaches its pinch-out edge on the Algonquin Arch, these units become less distinct and the formation terminology becomes less appropriate (Bailey and Cochrane, 1984).

Trap & Seal

Cambrian stratigraphic traps occur along the updip, pinch-out edge of porous strata (Figure 3a). The pinch-out edge is present in Southwestern Ontario on both sides of the Algonquin Arch. The Innerkip and Gobles pools are the best examples of Cambrian (Cambro-Ordovician) stratigraphic traps. These pools are formed by porous sandstones preserved within a north-to northwest trending embayment on the irregular surface of the Precambrian basement. The sand in the embayment extends 40 km north of the regional pinch-out edge on the southern flank of the Algonquin Arch. Some of the overlying Middle Ordovician Shadow Lake Formation sediments are also porous sandstones and are believed to form part of the reservoir, especially high on the crest of the Algonquin

Arch. Shales and sandy shales of the Middle Ordovician Shadow Lake Formation provide the top seal and create conditions favorable for stratigraphic entrapment of hydrocarbons. The reservoir is only a few metres in thickness.

A small number of Cambrian oil and gas pools have been discovered in structural traps on the Appalachian Basin side of the Algonquin Arch. Basement faulting and vertical movement of fault blocks that cut through and uplift overlying Cambrian strata create structural traps through juxtaposition of porous and permeable strata against non-permeable lithologies. One excellent example is the Clearville oil pool (Figure 3b). Here, the reservoir is formed by porous sandstone and sandy dolostone in the crest of a tilted horst block sealed by overlying shales of the Shadow Lake Formation and laterally by Middle Ordovician Gull River Formation limestones.

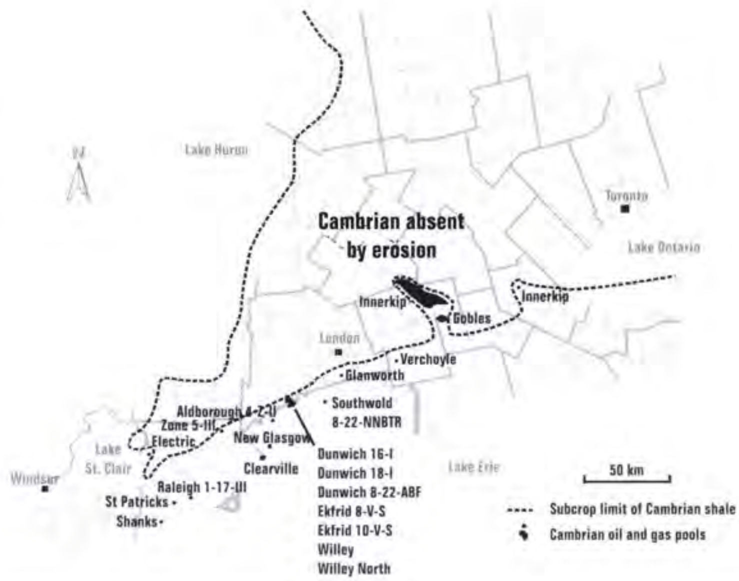


Figure 2. Cambrian oil and gas pools and the subcrop distribution of Cambrian sediments in Southwestern Ontario. Modified from Sanford and Quillian [1959] and Trevail [1990].

More detailed information pertaining to each reservoir type and most of the Cambrian pools can be found in Bailey and Cochrane (1984), Burgess (1962), Pounder (1964), and Trevail (1990).

Historical Production

There are 21 pools in Southwestern Ontario where wells have been completed to produce hydrocarbons from the Cambrian. Of these pools, 11 have produced commercial quantities and are still on production. Clearville, Dunwich 16-I, Dunwich 18-I, Dunwich 8-22-ABF, Ekfrid 8-V-S, Ekfrid 10-V-S and Willey North produce oil. Gobles and Willey produce oil and gas. Innerkip and Raleigh 1-17-XIII produce gas. Aldborough 4-Z-II and Shanks pools produced oil and gas for a short period of time before recompletion to produce from shallower formations. Glanworth, New Glasgow and Rockton pools produced gas, but were abandoned with no production records. Small quantities of oil and gas were produced from Electric, Southwold 8-22-NNBTR, St. Patricks, Verschoyle and Zone 5-III pools before abandonment.

The first Cambrian gas reservoir, the Electric pool, was discovered in 1948, with cumulative production of 789 E^6m^3 (28 Bcf) from Cambrian gas pools to the end of 2002. More than 89% of the Cambrian gas production has been derived from the Innerkip gas pool, which had a cumulative production of 702 E^6m^3 (25 Bcf) to the end of 2002. The Innerkip gas pool was discovered in 1961, but a major extension of the pool was discovered in 1986. Development of the Innerkip gas pool continued to the end of 2001, and in 2002 the pool produced 6.5% of Ontario's annual gas production.

The first Cambrian oil reservoir, the Shanks pool, was discovered in 1923, but it was the Gobles pool, discovered in 1960, that stimulated exploration for Cambrian oil. More than 93% of the Cambrian oil production has been derived from three pools: the Clearville, Gobles, and Willey pools, which had a cumulative production of 802 E^3m^3 (5.0 MMBO) to the end of 2002.

Reservoir Characteristics

Core analyses show average porosity of 9.2 to 11.8% to a maximum of 20% and average permeability of 1 to 67md and locally up to 300md for the major pools (Bailey and Cochrane, 1984). Within the known reservoirs, the Cambrian units are generally porous and permeable throughout, but mixed lithologies cause large fluctuations in porosity and permeability values. The presence of mixed grain sizes, filling of pores by clays, and cementation have resulted in reduction of primary interparticle porosity and permeability in the siliciclastic units. In the Innerkip pool, primary porosity has been substantially reduced by authigenic and diagenetic illite and chlorite clays and extensive quartz and K-feldspar overgrowths, calcite, dolomite and

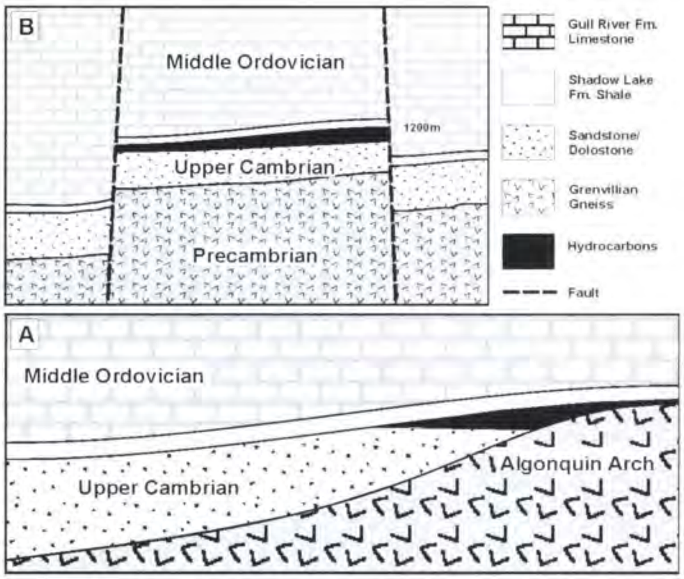


Figure 3. A. Diagrammatic cross-section through a Cambrian stratigraphic trap such as the Gobles and Innerkip pools. Porous Cambrian sandstone and/or dolostone and possible Middle Ordovician Shadow Lake Formation sandstone are filled with hydrocarbons where they pinch-out against the Algonquin Arch. B. Diagrammatic cross-section through a Cambrian fault trap such as the Clearville pool. Porous Cambrian sandstone and/or dolostone in the crest of the fault block are filled with hydrocarbons. Adapted from Bailey and Cochrane (1984).

anhydrite cements (Dorland, 2001). Secondary intercrystalline porosity and permeability by dolomitization has occurred in the carbonate units, which also has been reduced by clays and cements.

Current Exploration & Development and Exploration Methods

A total of 112 wells tested the Cambrian for oil and gas from 1992 to 2001. Extension and development of the Innerkip gas pool accounted for 104 of these wells, of which 72 were completed as gas producers. The other eight tests resulted in one new pool (Aldborough 4-Z-II), two oil and gas shows, one oil show, one gas show and three dry holes. No wells were drilled to test Cambrian targets for oil and gas in 2002. At the time of writing in 2003, one new pool well was completed in the Cambrian and four additional well licences with Cambrian targets have been issued.

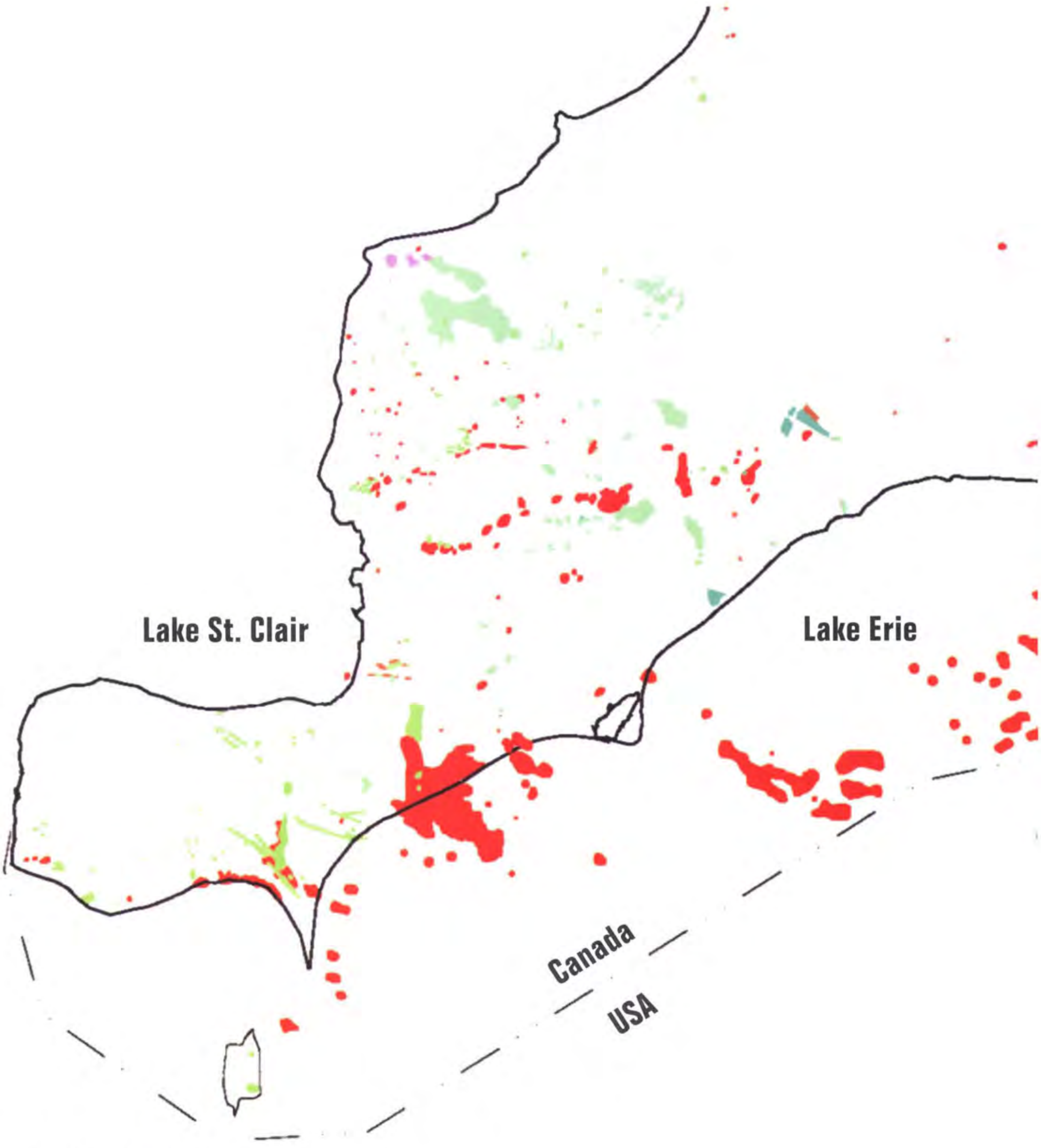
Stratigraphic prospects in the Cambrian play are usually defined with subsurface geology. Seismic is useful if the reservoir shows some degree of structural control as with Cambrian structural traps in tilted fault blocks. Seismic is of limited use along the pinch-out play because of the thin pay zone. Locating stratigraphic traps along the Cambrian pinch-out requires reconstruction of the meandering Cambrian erosional edge and, if possible, the Precambrian basement configuration as Cambrian sandstones tend to thicken in structural lows. Gravity and magnetic surveys may be of assistance in interpreting the Precambrian surface or finding areas deserving further investigation using seismic.

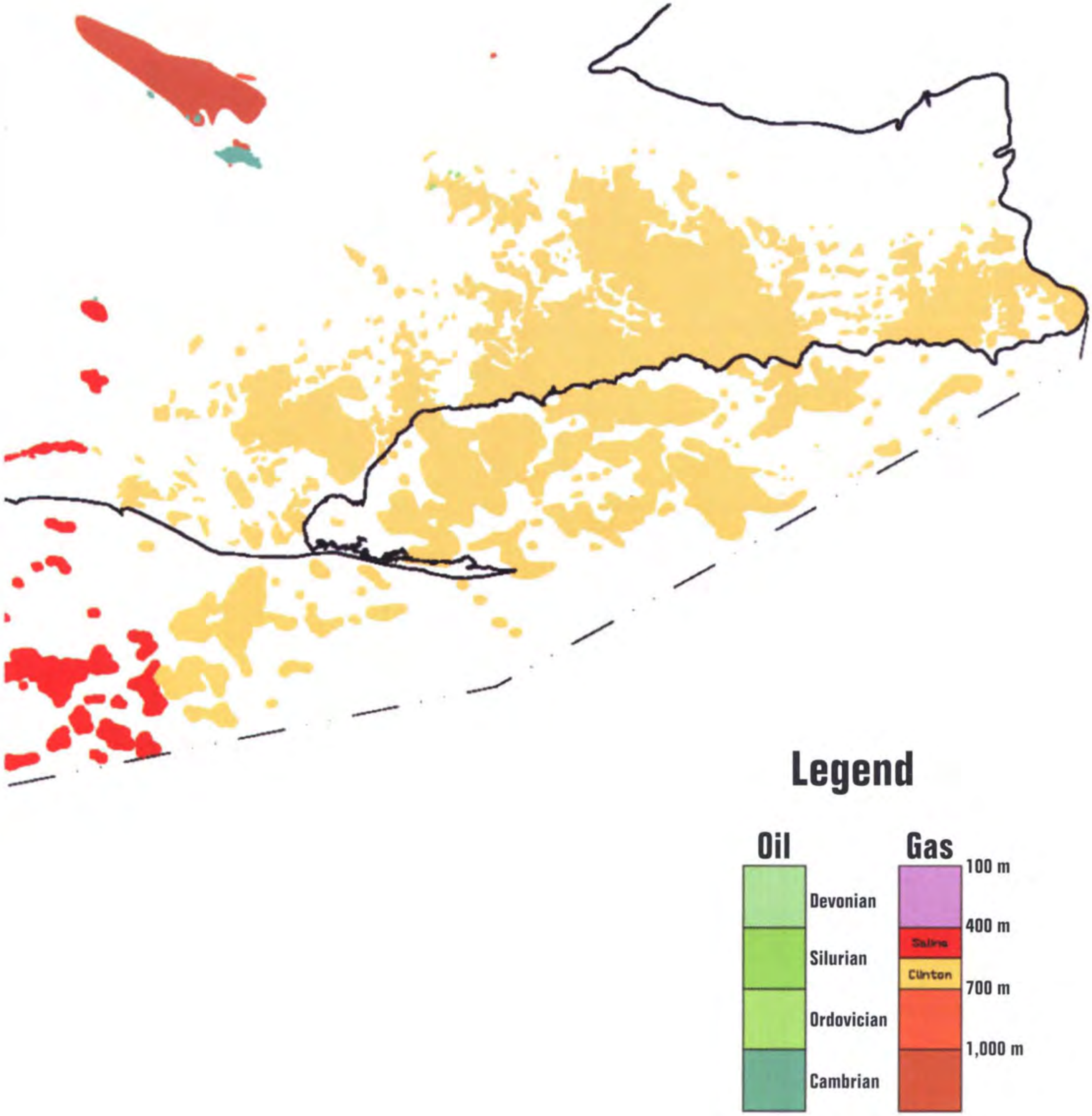
Future Potential

The Cambrian play is largely underdeveloped leaving considerable potential for additional discoveries. Cambrian sediments underlie an area of over 48,000 km^2 in Southwestern Ontario, but only 1,050 wells have tested Cambrian targets to the end of 2002. Potential oil and gas reserves for the Cambrian play were estimated by Bailey and Cochrane (1984) at 20.9 E^6m^3 (131.3 MMBO) and 6.3 E^9m^3 (222 Bcf), respectively. Total potential reserves for the stratigraphic pinch-out edge play are 3.0 E^6m^3 (19.1 MMBO) oil and 5.1 E^9m^3 (180 Bcf) gas and for the structural play area 17.9 E^6m^3 (112.3 MMBO) oil and 1.2 E^9m^3 (42 Bcf) gas. To the end of 2002, cumulative oil production is 802 E^3m^3 (5.0 MMBO) and cumulative gas production is 789 E^6m^3 (28 Bcf).

Possible areas for future exploration might also include areas over the Algonquin Arch where Cambrian strata are absent due to erosion during development of the Knox unconformity. Bruce Bailey, an Ontario geologist, has proposed that the Innerkip and Gobles pools may not contain Cambrian sediments, but are composed of sediments remaining after the Knox erosional episode and sandstones of the Middle Ordovician Shadow Lake Formation. Therefore exploration for an "Innerkip style" reservoir would not be confined to areas where the Cambrian pinches out against the Precambrian basement. Prospective areas could be any place where porous Paleozoic sediments are present at the Precambrian-Paleozoic unconformity since the unconformity has acted as a major fluid conduit throughout its history (Sanford et al., 1985; Harper et al., 1995). The Arthur pool, located in Wellington County on top of the Algonquin Arch 65 km north of the Innerkip pool, has anomalous production from the Shadow Lake Formation and is an example of a reservoir at the unconformity far removed from Cambrian strata.

OIL & GAS POOLS OF SOUTHERN ONTARIO




Legend
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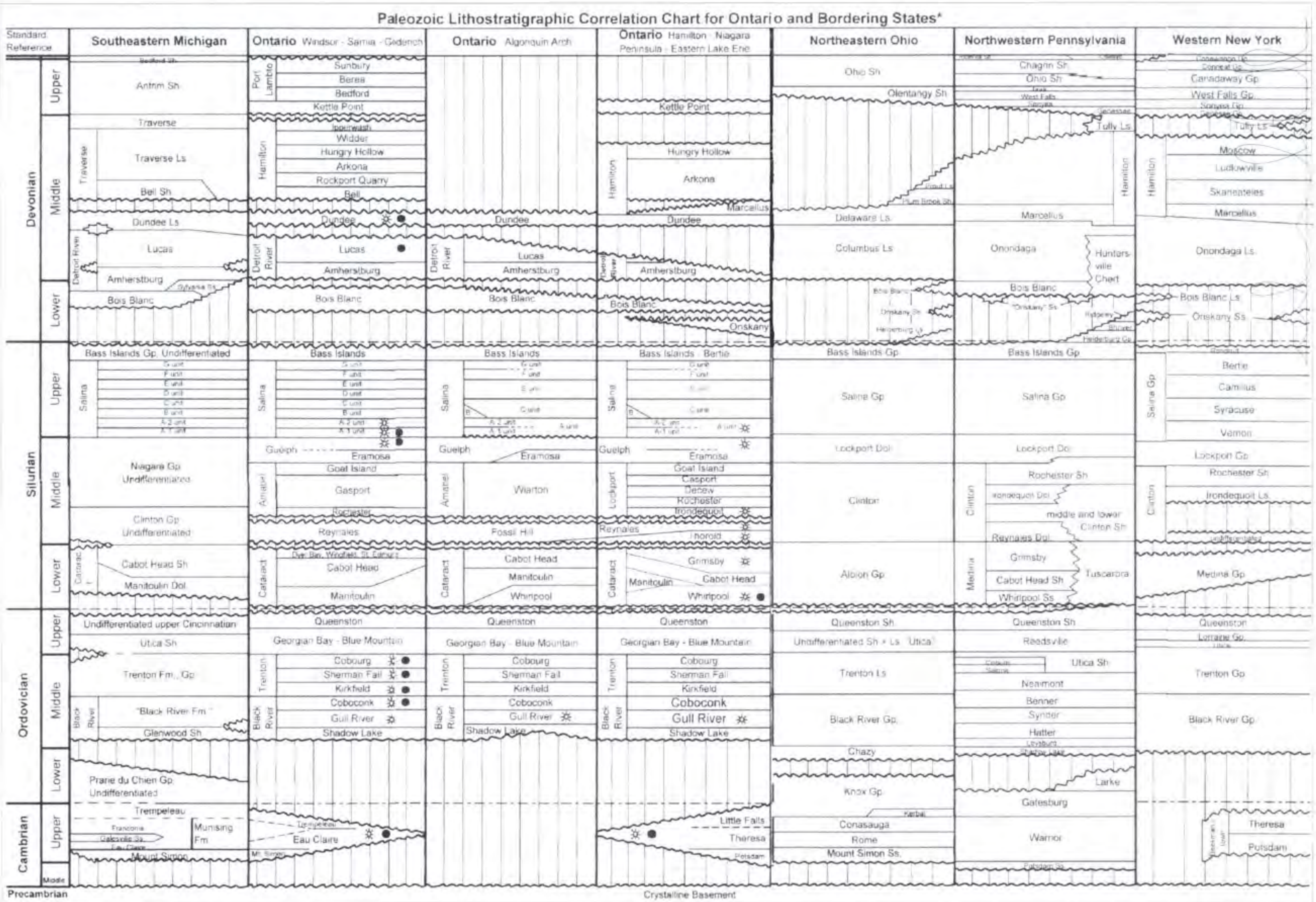

*Bordering States do not include symbols for oil & gas producing producing strata.

[Modified from Johnson et al. [1992]; Lindberg [1985]; Winder and Sanford [1972].]

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DIGITAL WELL DATABASE

Ontario 2002 Oil & Gas Exploration and Development Activity

By Terry Carter
Petroleum Resources Centre
Ministry of Natural Resources

OIL AND GAS drilling activity slowed in 2002 due to a lowering of prices late in 2001, which extended into the early part of the year. Prices for both oil and natural gas increased considerably late in the year due to both a rapid draw-down of natural gas storage levels in North America caused by cold winter temperatures and uncertainties about crude oil supplies due to the strike by Venezuelan oil workers and the possibility of war in Iraq.

EXPLORATION ACTIVITY

During 2002, a total of 105 licences to drill and operate new oil and gas wells were issued by the Ministry of Natural Resources, compared to 142 licences in 2001. At the time of writing, drilling was reported to be complete at 82 wells, consisting of 27 exploratory wells, 52 development wells and three service wells.

Exploratory drilling resulted in 18 wells reported as gas producers, including one private gas well and one well reported as an oil producer. Development drilling was very successful, with 12 wells reported to be oil producers, 22 as gas producers, six as private gas wells and one well completed for production of both oil and natural gas. Most of the successful oil wells were completed in Ordovician targets, while completions in Silurian sandstone reservoirs in Norfolk County dominated the gas-producing wells.

Horizontal drilling accounted for 26 of the 82 wells drilled in 2002, continuing the popularity of this technology.

Talisman Energy Inc. was the most active exploration company in Ontario's petroleum industry in 2002, with 28 wells drilled. Echo Energy Inc drilled 13 wells, and Pifher Resources Inc completed drilling at 11 wells.

Ordovician Play: Drilling was reported to be complete at one exploratory well and 14 development wells testing Ordovician targets in 2002. The one Ordovician exploratory well, TLM No.1 (Horiz #1) Mersea 2-18-D was reported to be completed as an oil producer.

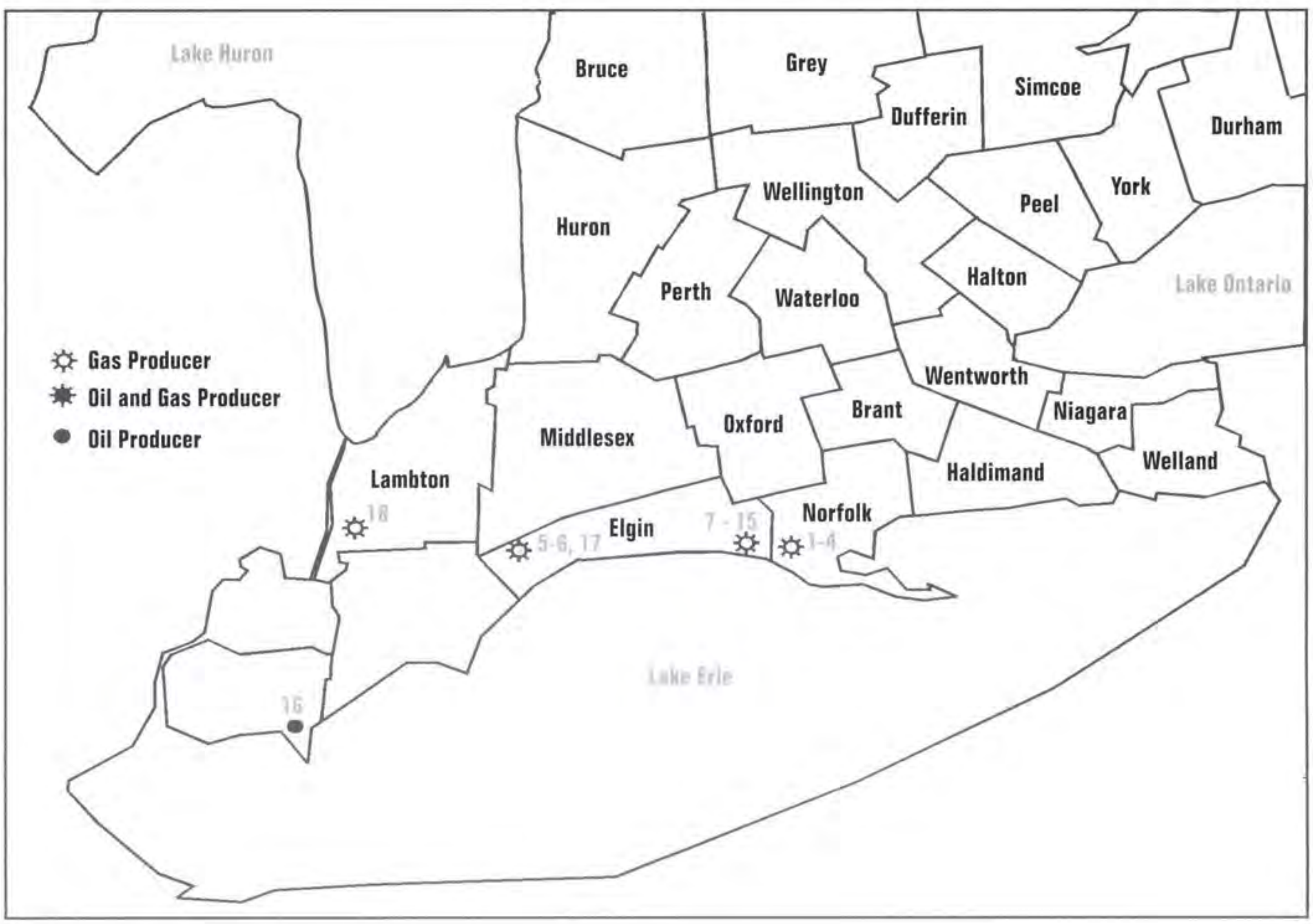
The Ordovician development drilling resulted in 12 new oil producers with one well still under evaluation. Successful oil wells were completed in the Mersea 4-240-STR, Mersea 6-16-B, Mersea 3-6-V (Wigle), Rochester 1-17-II EBR, and Rochester 7-17-IV EBR pools. All of these wells were drilled by Talisman Energy Inc.

Cambrian Play: No wells were drilled to test Cambrian targets for oil and natural gas potential in 2002. General Chemical Canada Ltd drilled one brine well on their property in Anderdon Township.

Silurian Carbonate Play: There were eight exploratory tests of Silurian Guelph Formation reef and/or Salina Formation structural trap targets in 2002. Kinetic #5 Sombra 4-2-XIII was completed as a natural gas well and REC #13 Aldborough 6-23-IV

Map #	Latitude	Longitude	Well Name	Target	Depth	Result	TD Date
1	42-37-25.947	80-40-53.421	Pifher 5 Houghton 3-2-I	CLI	445	GP-ACT	2002-11-05
2	42-38-34.708	80-40-49.343	Pifher 7 Houghton 3-5-I	CLI	424	GP-ACT	2002-12-12
3	42-38-55.398	80-40-47.883	Pifher 6 Houghton 3-6-I	CLI	445	GP-CAP	2002-12-06
4	42-41-30.110	80-42-49.06	Pifher 12 Houghton 6-11-WNR	CLI	417	GP-POT	2002-09-26
5	42-37-44.797	81-38-30.011	REC #11 Aldborough 1-21-IV	CLI	541	GP-ACT	2002-12-12
6	42-38-15.002	81-38-30.242	REC #14 Aldborough 5-22-III	CLI	544	GP-POT	2002-12-03
7	43-43-49.39	80-44-22.1	Echo 24 Bayham 6-24-SG	CLI	413	GP-CAP	2002-10-04
8	42-42-10.71	80-43-54.04	Echo 20 Bayham 6-26-V	CLI	414	GP-CAP	2002-11-05
9	42-43-18.23	80-47-14.63	Echo 22 Bayham 4-15-V	CLI	422.5	GP-POT	2002-11-05
10	42-42-4.53	80-46-15.43	Echo 18 Bayham 3-18-IV	CLI	423	GP-POT	2002-07-03
11	42-41-32.37	80-45-42.12	Echo 17 Bayham 6-20-IV	CLI	426	GP-POT	2002-09-26
12	42-43-2.25	80-45-3.66	Echo 21 Bayham 2-22-V	CLI	419.9	GP-POT	2002-07-02
13	42-41-22.33	80-44-31.01	Echo 16 Bayham 5-24-IV	CLI	418	GP-POT	2002-12-14
14	42-43-21.87	80-43-36.04	Echo 23 Bayham 8-27-SG	CLI	412	GP-POT	2002-07-02
15	42-42-2.88	80-43-19.81	Echo 19 Bayham 6-28-V	CLI	415	GP-POT	2002-12-16
16	41-59-32.83	82-31-17.902	TLM No.1 (Horiz #1) Mersea 2-18-D	ORD	2016	OP-ACT	2002-06-05
17	42-37-49.196	81-37-39.214	REC #13 Aldborough 6-23-IV	SAL	544	GP-POT	2002-03-19
18	42-44-8.784	82-27-4.538	Kinetic #5 Sombra 4-2-XIII	SAL	695	GP-ACT	2002-10-25

Figure 1: Screenshot from Petroleum GIS showing well locations in Essex County and survey grid for Lake Erie.



was reported to be a potential gas producer and is currently undergoing evaluation. The remaining six wells were all plugged and abandoned.

There were 13 development tests of Silurian GuelphSalina formation targets in 2002. Nine wells were drilled on offshore targets in Lake Erie by Talisman Energy Inc. to develop natural gas reservoirs in the Morpeth and Silver Creek platform reefs. Five of these wells were either completed for production or reported as potential gas producers. In onshore activity, Clearwood Resources Inc. completed an oil well on an extension of the Becher West oil pool. 748160 Ontario Inc. completed a well for production of natural gas in the Chatham 6-15-XII pool.

Silurian Sandstone Play: The interest in Silurian sandstone targets continued in 2002 as increasing natural gas prices improved the economics of this basin-centered tight gas play. A total of 17 exploratory and 24 development wells tested Lower Silurian sandstone targets in 2002. Sixteen of the exploratory wells were reported to be gas producers or potential gas producers. Successful wells were completed by Echo Energy Inc., Rowe Energy Corporation and Pifher Resources.

Twenty-three of the development wells were reported as gas producers or potential gas producers. Successful commercial gas wells were drilled in five different pools: Hemlock, Bayham, Lincoln, Houghton 5-8-ENR, and the Lake Erie-Maitland pool. Echo Energy and Pifher Resources were the most active companies in the play, accounting for 11 of the new gas wells. Successful wells were also completed by Hemlock Explorations, Talisman Energy and NRG Corp. Seven other wells were completed as private gas wells in parts of the Lincoln and Haldimand gas fields.

Devonian Play: One exploratory well was drilled to test the Devonian by Borders Exploration Ontario Inc. The well was reported to have encountered a show of natural gas and was plugged and abandoned shortly after reaching total depth.

Preliminary figures indicate that Ontario produced 211,000 m3 of oil valued at $55-million and 417 million m3 of natural gas valued at $83-million in 2002. This compares to production of 242,000 m3 of oil valued at $55-million and 394 million m3 of natural gas valued at $95-million in the previous year.

Drilling in 1896

Taking it Slow and [not so] Easy

By Mel McDonough
Canadian Drilling Rig Museum

IN THE 1850S, the way to dig oil and gas wells was pretty simple: start with a shovel and then deepen the well into bedrock using a spring pole. A spring pole was a "Y"-shaped tree branch used as a fulcrum, with a pole having a chisel-edge drill bit tied on one end. Stepping on the opposite end of the pole raised the bit; stepping off lowered the bit. The dropped bit slowly pounded and pulverized the rock cuttings into powder.

In 1858, after the discovery of the first commercial oil well at Oil Springs, Ontario, months of spring pole stepping were required to deepen the initial hand dug well to the oil pool deposit at the 60-foot level. This was a very tedious process. Indeed, it has been reported that in some foreign jurisdictions, well owners used convict labour to do the stepping process. Eventually, technology improved; a steam engine for power was introduced and the support tower, or derrick, incorporating the cable tool drilling string, was developed.

The Canadian Drilling Rig Museum at Rainham Centre, Haldimand County, Ontario has a fully operational and restored 1896 cable tool-drilling rig. This rig was discovered derelict and abandoned near the town of Acton, Ontario. A group of 16 dedicated individuals, being true Canadians, started on a cold, January winter day to recover the remaining metal parts out of the frozen field where the Southwestern Ontario-manufactured rig last operated and was abandoned in 1960.

In Rainham Centre, the refurbished metal parts, new cables, belts, and freshly sawed white oak timbers and red pine planks were reassembled into a functional drilling rig with a wooden 62-foot-high derrick. The rig was made operational for display at the September 1996 International Ploughing Match.

In 1997, the rig was moved to its current home, a 2½-acre site located in the Haldimand/Norfolk gas field near the Lake Erie shore. The rig is the centrepiece and heart of the museum — the only museum dedicated to preserving natural gas well drilling and heritage in Canada.

Many locally manufactured rigs operated in Southwestern Ontario in the late 1800s, and many men who learned the drilling technology went on to operate the first wells drilled in Alberta, the United States and South America. These early rigs tended to be powered by steam engines turning the canvas belt that operated an 8-foot diameter wooden band wheel that is at the centre of the drill string hoisting cable mechanisms. The engines operated at approximately 100-psi steam pressure and developed 18 to 20 horsepower. These first engines operated with open-fire wood or coal-fuelled boilers and had forges right on the wooden drilling platform, which was a potential major fire hazard to the wooden draw works and derrick, when high pressure, flammable gas was discovered. Blowout preventers did not exist until the 1920s, when the first annular rubber types around the drilling cables were installed. The Drilling Rig Museum's operating rig currently uses either a wood-fuelled steam or natural gas-fuelled internal combustion engine to turn the approximately 80-foot-long, 12-inch-wide power belt that operates the large, square, wooden walking beam and cable spools.

In the past, drilling rigs were skid-mounted and moved, as assembled and erect, by eight to 10 two-horse teams throughout the gas field, usually about 1,000 to 1,500 feet between well drilling sites. Wheel-mounted and breakdown rigs came quite a bit later. The museum's 1896 restored rig is mounted on skids. The rigs operated by raising and dropping a 2,000 lb. to 4,000 lb. drill string headed by a rock-breaking bit that is about eight inches in diameter, about four to six feet long, and weighing approximately 200 lbs. As the holes got deeper, six-inch diameter bits were used. The rigs were operated by a crew of four (two men on each 12-hour shift). The rigs drilled an average of 35 feet per day -- quite a different pace when compared to the 1,200 feet or more per day drilled with a modern hydraulic rotary bit-type rig, which was not introduced until the 1930s.

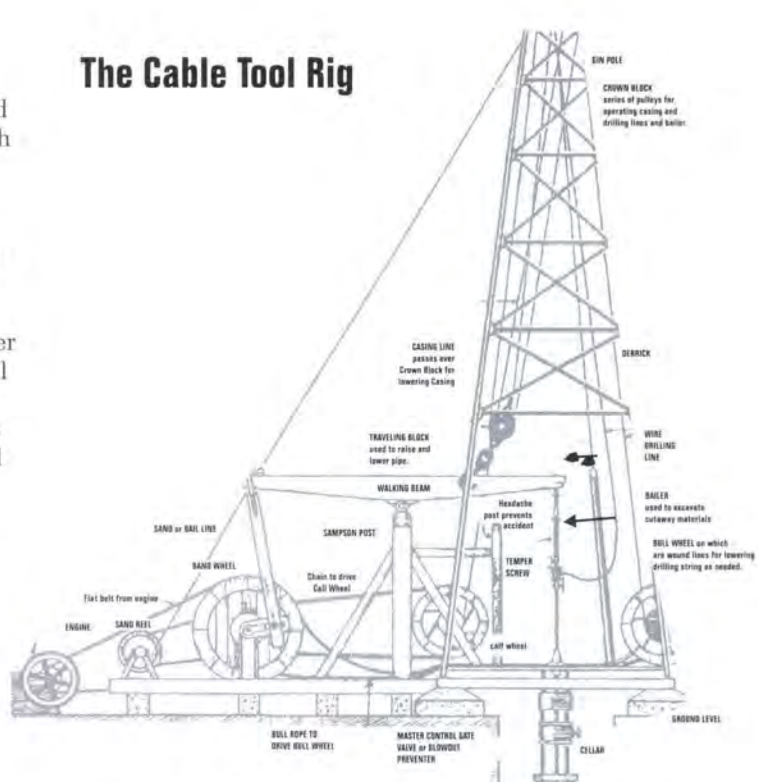
Gas wells in the area of the museum, on the northern shore of Lake Erie, were drilled to about 1,000 feet deep using these cable tool rigs. In Pennsylvania, on the south side of Lake Erie, the cable tool wells even reached 4,000 feet. The water table could be active until about the 700-foot level below the surface, and to keep the water out and the hole sides from caving in, the very early wells used casing pipes made from wood staves banded with iron rings produced by the local cooper or barrel maker. Water and rock cuttings from the drilling were removed from wells by a device called a bailer. Bailers were 30-foot long hollow pipes with a foot valve on the end. When they were inserted down the well, the foot valve opened to allow water in and, when withdrawn, the foot valve closed. The water and rock cuttings were dumped from the bailer at the surface into what was an early version of a mud pit.

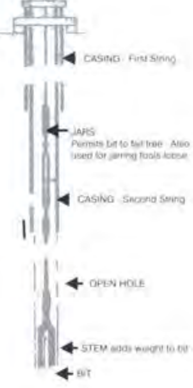
The bits at the end of the drill string were attached by screw threads and were dulled after pounding through about four to five feet of hard flint rock. They could be used for 50 to 75 feet of hole in softer shale rock before needing sharpening.

Resharpening drill bits was quite an art. The bits were heat softened and reshaped using 15 lb. sledgehammers on an anvil until they were the correct size of a gauge ring. Initially, the coal-fired heating forge was directly on the wooden drilling platform, but later was moved outside the rig for fire safety reasons. The museum has a separate, roofed, bit-dressing platform and forge adjacent to the drilling rig.

The proper heating of drill bits was very important. If improperly heated, the grain structure of the steel would be damaged and the final results would not be satisfactory. If the bit was reshaped and sharpened improperly, either it would be too soft and spread, subsequently jamming in the well hole, or, if reshaped too hard, it would become brittle and shatter. The bit sharpening procedure was as follows: heat the drill bit slowly to a uniform white-red heat in the forge fire; take it to an anvil; pound it with sledgehammers until it fit the gauge ring; reheat to

The Cable Tool Rig





The BAND WHEEL receives power from engine and operates in turn:

1. The walking beam set on the Sampson past, raising and dropping the "string" of drilling tools to drill the well.

2. The BULL WHEEL driven by a bull rope on which is wound the wire drilling line and that raises or lowers the drilling tools into the well.

3. The CALF WHEEL, on which is wound the wire casing line that raises or lowers casing into the well.

4. The SAND REEL, driven by chain from band wheel, bails out the cut-away material by means of the sand line and bailer.

To prevent walls caving in or water seeping in, wells are "CASED" with lengths of steel casing or pipe inserted as the hole is drilled.

FISHING is the name given to methods of recovering bits or larger parts of the drilling "string" that accidentally break off and become lodged in the well. If they cannot be recovered or drilled around, the well is abandoned.

BITS are of various designs to meet the different types of underground formations being drilled.

cherry red; scratch the bit with a metal file to create a temper-checking bluing line as it cooled; and then quench the bit in a water bath. The whole resharpening procedure took about 30 minutes and while heating, the bit was frequently turned to prevent one side heating more than the other. If a drill bit was red hot on one side and colder and blacker on the other side, the unequal expansion set up stresses that resulted in cracks, spalling, forging bursts, or serious injuries. The bit sharpening men needed skills similar to a good blacksmith.

The museum has expanded since 1997 and now consists of a main museum building and two other exhibit display buildings. On site are Case and Buffalo natural gas stationary engines, pump jacks, regulators, offshore well head fittings, a natural gas meter collection, gauges, antique gas lights and appliances, along with early Ontario gas well log records, pictures and other allied historical items.

A highlight in the museum's calendar is the annual Open House weekend, featuring the drilling rig in full operation and an active hot tool dressing display, which has proven to be a well-attended event. The next Open House weekend will be September 18 and 19, 2004.The public is invited to visit the museum. There is no admission fee, however, donations are welcome. Private, guided group tours are also available on request.

Contact us if you wish to become a supporting member of the Museum (annual fee of $25 for individual members and $300 for corporate members) or to set up a group tour.

Phone: 905-776-0919
Email: candrillmuseum@on.aibn.com
(To check the opening hours of the Museum, please visit our Web site, www.canadiandrillingrigmuseum.on.ca).

Canadian Drilling Rig Museum Inc.
RR#1
Selkirk, Ontario
N0A 1P0

Evaluating Southwestern Ontario's Groundwater

By Cliff Hanson and
Kerry O'Shea
Dillon Consulting Limited

THREE MAJOR REGIONAL groundwater evaluations for Essex, Kent, Elgin, Middlesex, and Lambton counties are being completed by Dillon Consulting Limited. While the principle focus of these studies is not directed toward the oil and gas industry, the area covered by these studies incorporates Ontario's major oil and gas producing region, and, as such, the presence of petroleum exploration, production, transportation, and brine disposal are recognized as potential threats to the quantity and quality of the regional groundwater resource. The groundwater studies, sponsored by the Ontario Ministry of Environment (MOE), compile the available geologic, hydrogeologic, water use, and water policy information into a document tailored to address each area's groundwater quality and quantity concerns. The study's principle goals are:

1) the characterization of the shallow stratigraphy (for example, generally less than 300 feet);
2) the lateral and vertical identification of groundwater aquifers;
3) the identification of groundwater flow direction;
4) the characterization of groundwater and surface water interaction; and
5) an assessment of the groundwater susceptibility to surface activities.

Oil and gas exploration and production represent important economic activities in this part of Southwestern Ontario. Oil and gas resources are typically found in geological formations that underlie the area's principle groundwater resources. Oil and gas wells must be drilled through and beyond the fresh-water-bearing zones that are tapped for potable water supplies. As a result, oil and gas wells can represent a threat to groundwater quality since they can intersect source aquifers. Surface works also have the potential to affect groundwater resources.

Generally, provincial laws and regulations and existing rules (for example, *Oil, Gas and Salt Resources Act*, *Ontario Energy Board Act* - 1998, Regulation 341 - Deep Well Disposal, and Ontario Regulation 210/01) provide a basis for the safeguarding of groundwater resources from oil and gas well activities. Instances of shallow groundwater contamination by the oil production processes, whether from oil and gas production or brine disposal, have been reported in Southwestern Ontario. In the future, as the potable groundwater resource becomes increasingly valuable to local users, the impacts on these resources from the oil and gas industry will likely come under increased scrutiny from local governments and the general public.

The groundwater studies represent an important tool for Ontario oil and gas production companies. Each groundwater study makes extensive use of the Geographic Information Data (GIS) process to compile and organize the large quantity of geologic and hydrogeologic information, MOE water well records, surface and near-surface geologic information, and the Ontario Ministry of Natural Resources (MNR) oil and gas well location and near-surface geology. The information contained in these studies is available for use by the industry. A review of this information can provide valuable insight into the potential for groundwater protection protocols being directed upon oil and gas activities.

The utilization patterns for both groundwater and surface water are defined within the groundwater studies. The specific locations for Permits to Take Water (PTTW) issued by MOE are mapped and water utilization patterns are displayed in a variety of manners. The identification of several poorly understood, large-scale aquifer units was accomplished, particularly in the southern portions of Essex and in southern Kent and Elgin counties. This information will be readily available from local government agencies.

The study data also provide a comprehensive evaluation of groundwater presence, identifies wellhead protection areas and documents the presence of groundwater aquifers within prospective drilling regions. Additionally, the studies provide an excellent review of the local and regional groundwater protection standards presently in force and a road map toward future protection efforts. It is highly likely that local and regional governments will use the information as the basis for future groundwater protection policies. OOG

Providing a Program for

The Give and Take of Information

By Andrew Hewitt
Manager, Petroleum Resources Centre

TO THE PEOPLE running the petroleum resources program of the Ministry of Natural Resources (MNR), the industry in Ontario is about giving and taking...information, that is, and all for the benefit of all stakeholders. Responsible for regulating the oil, gas and storage tenures on Crown lands, as well as some industry activities associated with the drilling of wells into Ontario's sedimentary rocks, the program's objectives are to ensure that:

1. The exploration, development and production of crude oil, natural gas, salt-solution mining, and underground storage do not result in a hazard to public safety or polluting of the environment, including surface waters and underground drinking water aquifers;
2. Ontarians receive a fair share of the value of natural resources produced on Crown land;
3. Correlative rights are protected through optimal drainage areas (spacing units) on Crown and freehold land;
4. Information necessary to make decisions based on high-quality science and information for oil, gas, salt solution-mining, and underground storage resource management are collected; and
5. All operators follow the regulatory requirements for drilling wells and production facilities, and follow through with site clean up and the plugging of unused wells.

The functions of The Petroleum Resources Centre (PRC) include:

a) Proponent-driven technical reviewing of applications for life-cycle well licences;
b) Conducting regular field inspection and enforcement activities to ensure that that the requirements of the *Oil, Gas and Salt Resources Act* (OGSRA), its regulations and standards are met; and
c) Conducting tenders for oil, gas and storage on Crown lands.

Currently, 3,700 wells are active at several hundred locations. About 100 new wells are drilled every year for production of oil, gas, salt, and hydrocarbon storage. An estimated 50,000 petroleum wells have been drilled in Ontario.
The PRC recognizes the many historical accomplishments of the oil and gas industry in Ontario, including the first commercial oil well at Oil Springs (drilled in 1858), the first salt solution mining well (completed in 1866), and the first well on Lake Erie (drilled in 1913). Natural gas storage first occurred in 1915, when gas was transferred from a high-pressure pool to a lower pressure pool. However, natural gas storage in reefs first started in 1942. Solution-mined caverns were first used for hydrocarbon storage in 1952.

The oil and gas industry provides a significant contribution to the local and provincial economies, with the production of oil, gas and salt generating more than $100-million annually. Twenty-nine designated storage areas for natural gas are storing more than $1-billion worth of natural gas —

keeping the price lower for consumers and providing reliability during the cold months. Also, 73 solution-mined caverns are being used for liquified petroleum gas and petrochemicals, with an estimated storage value of more than $1-billion.

The collection and dissemination of information is a key function of the PRC. Data collection began in the late 1800s and consists of geological, drilling and engineering information on more than 20,000 wells drilled in all parts of Ontario for the purpose of exploring for or producing hydrocarbons, underground storage of hydrocarbons, disposal of oil-field fluids, and production of salt by the solution-mining method. Information collected includes: well location; well status; operator; drilling dates; depths and results; geological formation tops; well construction; oil/gas/water intervals; geophysical well logs; drill core and cuttings; core analyses; oil/gas/water analyses; drill stem and production tests; and monthly production volumes and pressures. The PRC, in cooperation with the Oil, Gas and Salt Resources Library, provides geological analysis and information required for assessing oil, gas and salt resource industries in Ontario.

Currently, 440,000 hectares are under tenures on Lake Erie, and with the increased technologies there is further potential to develop open lands on Lake Erie, Lake St. Clair, Lake Huron, and the Hudson Bay Lowlands.

To maintain long-term viability of the oil and gas industry, the PRC's compliance program is intended to ensure that operations comply with the OGSRA, its regulations and its standards. This process involves reviewing industry compliance with requirements for data and record submissions, and field inspections of wells and associated facilities.

The Petroleum Resources Centre also promotes the responsible use of the resource by working with its stakeholders, such as municipalities, industry, agricultural associations, academic institutions, and the general public. We believe that effective consultation and communication are key in recognizing the existing industry and moving forward into the next generation.

Our challenge is to seek future oil and gas reserves by developing newer plays through the use of information and GIS technologies, and also to address, through cooperation among industry, farmers associations and the government, the issue of the estimated 20,000 orphan wells. We will seek ongoing improvements in updating spacing and pooling requirements, in continuing to seek compliance with the OGSRA, and in implementing functional and quality electronic information for the industry and the general public.

We are encouraged by the partnerships with our stakeholders, including the Ontario Petroleum Institute (OPI), in ensuring that the resource is properly extracted and the rights of landowners and the general public are respected. The operation of the Oil, Gas and Salt Resources Library by the OPI is providing a valued educational and information service to industry, government and the public. We look forward to ongoing opportunities to develop these partnerships in the future.

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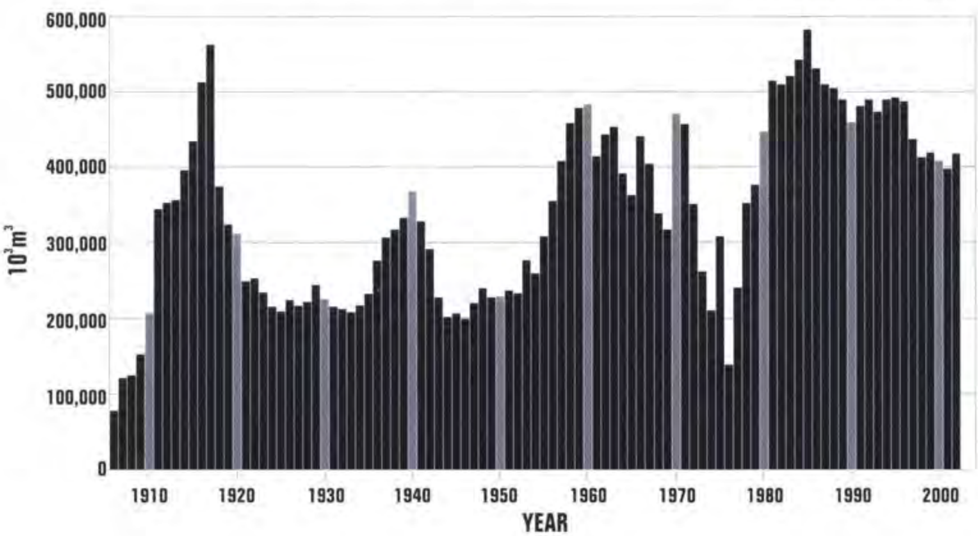
Historical Natural Gas Production 1905 - 2002

O&G

Year	Number of Producing Gas Wells	Gas Production 10^3 m^3	Avg. 10^3 m^3 Per well	Cumulative Gas Production 10^3 m^3
1905				1,258,145
1906		71,788		1,329,933
1907		117,728		1,447,661
1908		126,994		1,574,655
1909		152,630		1,727,285
1910		205,754		1,933,039
1911		348,770		2,281,808
1912		352,820		2,634,629
1913		355,752		2,990,381
1914		398,369		3,388,750
1915		430,932		3,819,681
1916		507,893		4,327,574
1917		567,305		4,894,879
1918		370,171		5,265,050
1919		327,563		5,592,613
1920		303,938		5,896,551
1921	1915	241,700	126	6,138,251
1922	1907	242,721	127	6,380,972
1923	2004	230,260	115	6,611,233
1924	2210	208,802	94	6,820,035
1925	2125	205,583	97	7,025,618
1926	2126	220,291	104	7,245,909
1927	2217	207,111	93	7,453,020
1928	2272	216,219	95	7,669,239
1929	2349	243,143	104	7,912,382
1930	2452	225,020	92	8,137,402
1931	2606	210,179	81	8,347,581
1932	2707	209,234	77	8,556,815
1933	2821	203,016	72	8,759,831
1934	2977	217,639	73	8,977,470
1935	3127	231,122	74	9,208,592
1936	3218	283,469	88	9,492,061
1937	3252	304,420	94	9,796,482
1938	3273	310,269	95	10,106,751
1939	3322	338,987	102	10,445,738
1940	3382	369,775	109	10,815,513
1941	3429	335,082	98	11,150,595
1942	3503	296,784	85	11,447,379
1943	3511	224,198	64	11,671,577
1944	3500	200,632	57	11,872,209
1945	3612	203,960	56	12,076,169
1946	3696	199,748	54	12,275,917
1947	3793	220,558	58	12,496,475
1948	3785	243,348	64	12,739,824
1949	3812	227,309	60	12,967,132
1950	3938	226,891	58	13,194,024
1951	3951	239,167	61	13,433,191
1952	3846	235,183	61	13,668,374
1953	NA	268,618	NA	13,946,992

Year	Number of Producing Gas Wells*	Gas Production 10^3 m^3	Avg. 10^3 m^3 Per well	Cumulative Gas Production 10^3 m^3
1954	3211	283,726	88	14,230,718
1955	3103	307,438	99	14,538,156
1956	3083	362,925	118	14,901,082
1957	3057	407,947	133	15,309,029
1958	2931	457,438	156	15,766,466
1959	2900	477,019	164	16,243,485
1960	2792	481,207	172	16,724,692
1961	2728	412,005	151	17,136,697
1962	2472	443,282	179	17,579,979
1963	2449	450,981	184	18,030,960
1964	2262	391,377	173	18,422,336
1965	2208	359,749	163	18,782,085
1966	2098	440,134	210	19,222,219
1967	2043	402,769	197	19,624,989
1968	1986	341,799	172	19,966,788
1969	1834	318,345	174	20,285,133
1970	1672	471,643	282	20,756,776
1971	1439	457,997	318	21,214,773
1972	1292	350,561	271	21,565,333
1973	1187	269,911	227	21,835,244
1974	1130	213,506	189	22,048,750
1975	1083	309,778	286	22,358,528
1976	1070	140,439	131	22,498,966
1977	1034	241,522	234	22,740,489
1978	1017	352,997	347	23,093,485
1979	1078	377,576	350	23,471,061
1980	1066	448,904	421	23,919,965
1981	1141	517,701	454	24,437,666
1982	1086	512,663	472	24,950,328
1983	1169	522,960	447	25,473,288
1984	1128	545,009	483	26,018,297
1985	1196	588,746	492	26,607,043
1986	1266	531,727	420	27,138,770
1987	1251	511,331	409	27,650,101
1988	1220	503,422	413	28,153,523
1989	1238 (264)	488,897	395	28,642,420
1990	988 (410)	456,750	462	29,099,171
1991	1186 (590)	477,489	403	29,576,660
1992	1132 (490)	485,183	429	30,061,843
1993	1123 (432)	474,672	423	30,536,515
1994	1239 (399)	484,723	391	31,021,238
1995	1196 (532)	491,413	411	31,512,651
1996	1274 (483)	484,397	380	31,997,048
1997	1257 (295)	434,946	346	32,431,994
1998	1218 (306)	412,120	338	32,844,114
1999	1228 (364)	421,869	344	33,265,983
2000	1424 (591)	420,023	323	33,686,007
2001	1285 (318)	397,840	310	34,071,073
2002	1316 (267)	419,727	319	34,490,800

* Suspended wells indicated in brackets.



Historical Natural Gas Production 1906 - 2002

Annual/Cumulative Lake Erie Natural Gas Production

O&G

Year	Number of Active Wells	Number of Suspended Wells	Annual Production ($10^3 m^3$)	Average Production/Well ($10^3 m^3$)	Cumulative Production ($10^3 m^3$)
1957					
1958					981,592.7
1959					
1960	127	17	102,021.4	803.3	1,083,614.1
1961	145	41	92,750.8	639.7	1,176,364.8
1962	172	49	87,687.6	509.8	1,264,052.5
1963	168	74	100,090.7	595.8	1,364,143.1
1964	196	63	97,954.7	499.8	1,462,097.8
1965	225	57	105,758.6	470.0	1,567,856.4
1966	228	60	125,980.1	552.5	1,693,836.5
1967	200	86	117,186.6	585.9	1,811,023.1
1968	222	81	103,471.6	466.1	1,914,494.7
1969	223	107	117,103.9	525.1	2,031,598.7
1970	250	90	144,800.2	579.2	2,176,398.8
1971	268	47	143,558.8	535.7	2,319,957.6
1972	272	59	175,858.4	646.5	2,495,816.0
1973	285	49	181,161.6	635.7	2,676,977.6
1974	291	73	151,038.1	519.0	2,828,015.7
1975	272	107	160,309.0	589.4	2,988,324.7
1976	279	114	80,587.0	288.8	3,068,911.7
1977	320	141	157,891.5	493.4	3,226,803.2
1978	328	100	212,634.5	648.3	3,439,437.7
1979	344	119	213,870.3	621.7	3,653,308.0
1980	376	N/A	272,426.3	724.5	3,925,734.3
1981	474	N/A	324,283.3	684.1	4,250,017.6
1982	444	N/A	353,013.6	795.1	4,603,031.2
1983	527	161	383,651.0	728.0	4,986,682.2
1984	585	148	407,790.0	697.1	5,394,472.2
1985	610	153	430,784.8	706.2	5,825,257.0
1986	622	123	398,031.1	639.9	6,223,288.1
1987	601	120	389,998.9	648.9	6,613,287.0
1988	628	117	383,571.8	610.8	6,996,858.8
1989	612	142	357,289.5	583.8	7,354,148.3
1990	456	253	324,421.3	711.5	7,678,569.6
1991	503	280	343,385.3	682.7	8,021,954.9
1992	511	289	323,477.5	633.0	8,345,432.4
1993	489	237	300,024.7	613.5	8,645,457.1
1994	538	190	284,697.1	529.2	8,930,154.2
1995	554	248	291,474.3	526.1	9,221,628.5
1996	582	239	302,683.6	520.1	9,524,312.1
1997	551	200	288,255.4	523.1	9,812,567.5
1998	553	210	281,939.1	509.8	10,094,506.6
1999	517	243	285,444.5	552.1	10,379,951.1
2000	631	238	279,371.2	548.9	10,659,322.3
2001	495	233	268,670.6	542.8	10,927,992.9
2002	485	185	286,362.2	590.5	11,214,369.1

Top Producing Natural Gas Pools, 1992-2002

	County Produced	Pool Name	Geological Age	Natural Gas $10^3 m^3$
Offshore	Lake Erie	Silver Creek + Clear Creek (Port Stanley)	Silurian Salina/Guelph	946,395
	Lake Erie	Morpeth	Silurian Salina/Guelph	945,088
	Lake Erie	Maitland + Leepfrog (Maitland)	Silurian Clinton/Cataract	923,691
	Lake Erie	Dover + Selkirk (Nanticoke)	Silurian Clinton/Cataract	143,254
	Lake Erie	D'Clute + Tilbury (Port Alma)	Silurian Salina/Guelph	123,546
	Lake Erie	Lake Erie 286-D (Port Stanley)	Silurian Salina/Guelph	22,642
Onshore	Oxford	Innerkip	Cambrian	538,084
	Norfolk	Norfolk	Silurian Clinton/Cataract	161,454
	Kent	Dover 7-5-V E	Ordovician	126,527
	Kent	Dover	Ordovician	49,141
	Kent	Chatham 7-17-XII	Silurian Salina/Guelph	45,260
	Essex	Mersea 6-23-VII	Ordovician	41,220
	Kent	Romney 3-8-II	Ordovician	40,911
	Essex	Rochester 1-17-II	Ordovician	37,805
	Huron	Dungannon	Silurian Salina/Guelph	33,050
	Kent	Zone	Silurian Salina/Guelph	30,792
	Elgin	Townline	Silurian Salina/Guelph	27,761
	Lambton	Sarnia 2-11-VIII	Silurian Salina/Guelph	27,189
	Lambton	Sombra 4-16-IX	Silurian Salina/Guelph	26,367
	Essex	Mersea 3-6-V	Ordovician	21,631
	Lambton	Sombra 8-6-XV	Silurian Salina/Guelph	21,463

Top Producing Natural Gas Pools, 2001-2002

	County Produced	Pool Name	Geological Age	Natural Gas $10^3 m^3$
Offshore	Lake Erie	Morpeth	Silurian Salina/Guelph	192,739
	Lake Erie	Silver Creek + Clear Creek (Port Stanley)	Silurian Salina/Guelph	176,644
	Lake Erie	Maitland + Leepfrog (Maitland)	Silurian Clinton/Cataract	127,882
	Lake Erie	Dover + Selkirk (Nanticoke)	Silurian Clinton/Cataract	29,423
	Lake Erie	D'Clute + Tilbury (Port Alma)	Silurian Salina/Guelph	17,338
	Lake Erie	Lake Erie 286-D (Port Stanley)	Silurian Salina/Guelph	11,022
Onshore	Oxford	Innerkip	Cambrian	55,165
	Norfolk	Norfolk	Silurian Clinton/Cataract	26,641
	Kent	Romney 3-8-II	Ordovician	16,866
	Kent	Dover 7-5-V E	Ordovician	10,821
	Kent	Romney 5-15-I	Ordovician	10,043
	Oxford	Blenheim 8-13-X	Cambrian	8,587
	Huron	Dungannon	Silurian Salina/Guelph	7,592
	Elgin	Townline	Silurian Salina/Guelph	7,427
	Essex	Mersea 3-6-V	Ordovician	7,104
	Essex	Rochester 1-17-II EBR	Ordovician	6,788
	Norfolk	South Walsingham 5-6-VI	Silurian Clinton/Cataract	4,919
	Essex	Mersea 3-4-IV	Ordovician	4,320
	Essex	Gosfield North 2-21-VI	Ordovician	4,214
	Lambton	Enniskillen 3-1-II	Silurian Salina/Guelph	4,198
	Kent	Zone	Silurian Salina/Guelph	4,105

Natural Gas Production by County, 1989-2002

COUNTY	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Brant	443.0	162.8	625.9	170.0	171.7	235.2								
Elgin	2,984.5	2,419.5	2,525.4	2,454.8	2,561.2	2,649.6	2,481.5	3,322.8	3,011.6	3,973.5	4,107.6	3,185.3	4,795.9	5,336
Essex				10,493.6	9,171.7	16,219.8	21,773.6	19,762.1	15,185.4	15,966.4	20,442.6	17,211.9	18,707.5	18,115.7
Haldimand	1,211.7	1,243.8	1,675.4	1,593.0	1,142.7	1,017.5		380.8	341.5	40.0	1,266.1	1,443.0	302.7	1,387.2
Halton									155.8					
Huron	2,713.9	2,752.2	3,641.2	3,150.7	2,982.9	3,564.6	1,853.9	1,910.5	8,551.2	8,491.3	10,721.4	10,814.9	9,282.4	10,376.1
Kent	38,550.7	33,028.2	42,645.7	50,229.5	36,938.4	34,326.1	34,334.5	50,037.5	41,948.2	25,508.8	27,600.7	29,039.3	28,561.7	29,269.6
Lambton	43,066.7	47,651.9	38,416.2	29,055.1	34,423.0	41,455.7	34,905.1	31,688.8	18,279.5	16,378.6	14,506.4	18,297.9	10,576.2	15,134.2
Lincoln	248.1	197.4	98.7		25.1	16.2	19.0	23.8	492.8				1,384.7	1,013.3
Middlesex										95.2	275.4	256.2	251.3	257.4
Norfolk	22,214.0	22,052.1	20,402.0	21,065.4	21,265.5	20,012.5	18,951.3	19,825.4	18,253.3	16,690.5	18,302.5	18,808.7	20,089.0	22,668.8
Oxford	19,031.3	21,951.7	22,781.3	42,306.9	65,332.3	79,988.3	85,142.8	54,200.7	39,966.8	42,897.2	39,202.1	41,590.3	33,827.1	30,599.9
Welland	867.8	777.3	725.3	687.9	55.8	16.7	7.3	21.7	13.2					
Wellington	275.8	91.9	566.8	499.1	576.7	523.5	470.1	539.6	490.8	139.6		4.7	1,265.8	1,197.2
Lake Erie/Offshore	357,289.5	324,421.3	343,385.3	323,477.5	300,024.7	284,697.1	291,474.3	302,683.6	288,255.4	281,939.1	285,444.5	279,371.2	268,670.6	286,376.2
Total	488,897.0	456,750.1	477,489.2	485,183.5	474,671.7	484,722.8	491,413.4	484,397.3	434,945.5	412,120.2	421,869.3	420,023.4	397,709.9	421,731.6

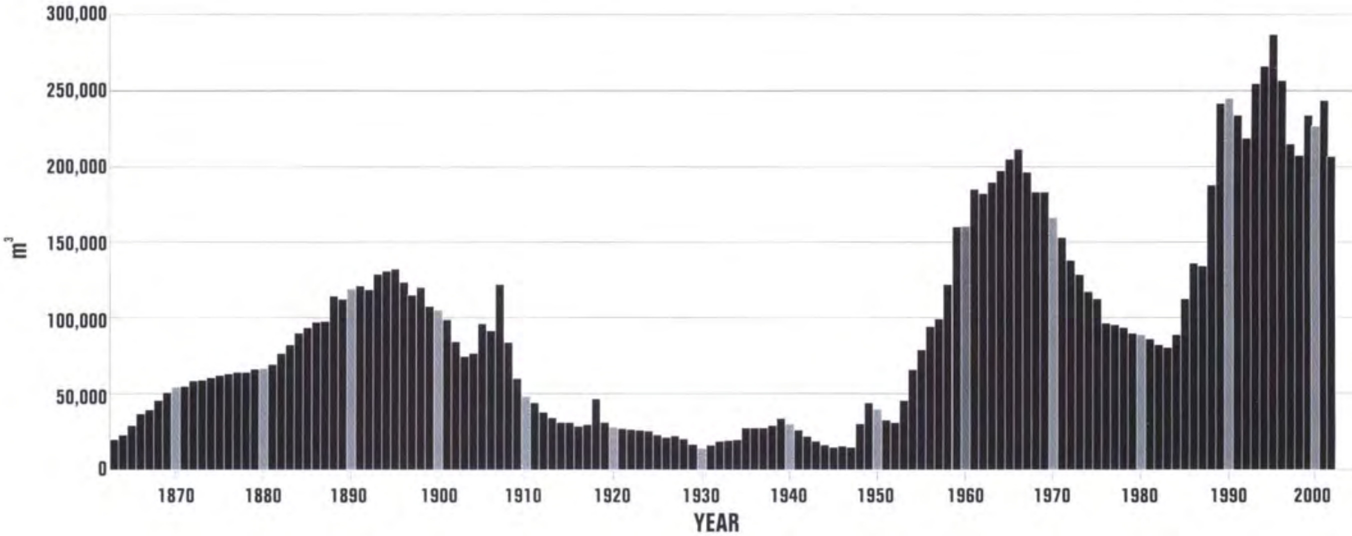
Historical Oil Production 1863 - 2002

O&G

Year	Number of Producing Oil Wells	Oil Production (m^3)	Avg. Oil Production per Well (m^3)	Cumulative Oil Production (m^3)
1863		18,125		18,125
1864		23,530		41,655
1865		28,936		70,590
1866		34,341		104,931
1867		39,747		144,678
1868		45,152		189,831
1869		50,558		240,388
1870		56,774		297,163
1871		57,911		355,073
1872		59,047		414,120
1873		60,183		474,303
1874		61,319		535,623
1875		62,456		598,078
1876		63,592		661,670
1877		64,728		726,398
1878		65,865		792,263
1879		67,001		859,264
1880		68,137		927,401
1881		72,673		1,000,074
1882		77,222		1,077,295
1883		81,765		1,159,060
1884		87,216		1,246,276
1885		93,120		1,339,396
1886		97,663		1,437,059
1887		98,572		1,535,631
1888		115,266		1,650,896
1889		112,881		1,763,777
1890		119,240		1,883,017
1891		123,215		2,006,232
1892		121,625		2,127,857
1893		127,190		2,255,047
1894		131,164		2,386,211
1895		132,754		2,518,965
1896		124,010		2,642,975
1897		119,240		2,762,216
1898		122,420		2,884,636
1899		108,906		2,993,542
1900		107,316		3,100,858
1901		99,367		3,200,225
1902		84,263		3,284,488
1903		75,519		3,360,007
1904		77,109		3,437,115
1905		96,187		3,533,302
1906		93,637		3,626,939
1907		123,990		3,750,929
1908		84,097		3,835,027
1909		66,880		3,901,906
1910		49,987		3,951,893
1911		45,889		3,997,782
1912		38,306		4,036,088
1913		35,958		4,072,045
1914		33,784		4,105,829
1915		34,094		4,139,923
1916		31,301		4,171,224
1917		32,273		4,203,497
1918		45,909		4,249,406
1919		34,993		4,284,399
1920		28,896		4,313,295
1921	3465	27,482	8	4,340,777
1922	3506	26,190	7	4,366,967
192	33407	25,342	7	4,392,310
1924	3379	24,534	7	4,416,844
1925	2884	22,934	8	4,439,778
1926	2752	21,777	8	4,461,555
1927	2708	22,195	8	4,483,750
1928	2641	21,330	8	4,505,080
1929	2443	19,257	8	4,524,338
1930	2222	18,650	8	4,542,987
1931	2208	19,454	9	4,562,442
1932	2056	20,723	10	4,583,164
1933	2151	21,631	10	4,604,796

Year	Number of Producing Oil Wells*	Oil Production (m^3)	Avg. Oil Production per Well (m^3)	Cumulative Oil Production (m^3)
1934	2201	22,478	10	4,627,274
1935	2109	26,239	12	4,653,514
1936	2079	26,311	13	4,679,825
1937	2082	26,265	13	4,706,090
1938	2110	27,448	13	4,733,538
1939	2065	32,812	16	4,766,350
1940	2028	29,833	15	4,796,183
1941	1956	25,348	13	4,821,531
1942	1852	22,870	12	4,844,401
1943	1728	21,064	12	4,865,465
1944	1609	19,884	12	4,885,349
1945	1579	18,017	11	4,903,367
1946	1610	19,568	12	4,922,935
1947	1559	20,874	13	4,943,809
1948	1489	28,139	19	4,971,948
1949	1518	41,443	27	5,013,391
1950	1513	39,851	26	5,053,243
1951	1471	31,348	21	5,084,590
1952	1381	30,496	22	5,115,086
1953	1423	47,646	33	5,162,732
1954	1396	65,578	47	5,228,311
1955	1433	83,549	58	5,311,860
1956	1422	94,338	66	5,406,198
1957	1428	99,155	69	5,505,353
1958	1412	123,746	88	5,629,099
1959	1384	159,239	115	5,788,338
1960	1339	159,787	119	5,948,125
1961	1312	182,690	139	6,130,815
1962	1300	180,377	139	6,311,192
1963	1311	191,639	146	6,502,831
1964	1243	198,207	159	6,701,038
1965	1234	203,371	165	6,904,408
1966	1183	210,464	178	7,114,873
1967	1068	197,192	185	7,312,064
1968	1041	182,959	176	7,495,024
1969	929	184,726	199	7,679,749
1970	920	166,693	181	7,846,442
1971	873	152,326	174	7,998,768
1972	878	139,608	159	8,138,376
1973	756	128,565	170	8,266,941
1974	673	116,707	173	8,383,649
1975	693	111,978	162	8,495,627
1976	695	98,812	142	8,594,439
1977	658	98,372	150	8,692,811
1978	715	95,144	133	8,787,956
1979	760	92,932	122	8,880,888
1980	805	93,299	116	8,974,186
1981	872	90,105	103	9,064,291
1982	917	85,711	93	9,150,002
1983	953	84,612	89	9,234,614
1984	961	90,333	94	9,324,947
1985	1102	112,954	102	9,437,901
1986	1069	135,816	127	9,573,717
1987	1175	135,635	115	9,709,353
1988	1107	190,573	172	9,899,925
1989	1092 (487)	243,699	223	10,143,624
1990	1045 (294)	247,825	237	10,391,448
1991	1051 (290)	235,615	224	10,627,063
1992	1099 (190)	222,320	202	10,849,384
1993	1209 (230)	254,370	210	11,103,754
1994	1142 (145)	263,873	231	11,367,627
1995	1130 (362)	288,009	255	11,655,636
1996	1130 (188)	257,395	228	11,913,031
1997	1213 (190)	217,099	179	12,130,129
1998	1203 (185)	211,149	176	12,341,279
1999	1170 (190)	238,167	204	12,579,445
2000	1274 (214)	232,306	182	12,811,752
2001	1211 (239)	243,461	201	13,055,213
2002	1204 (183)	212,151	176	13,267,364

* Suspended wells in brackets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Oil Production by County 1989 - 2002

COUNTY	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Elgin	22,870.5	20,349.2	18,711.8	17,987.4	17,232.6	15,584.3	14,403.9	13,739.4	12,548.6	3,859.2	10,521.4	10,029.0	9,235.8	9,277.9
Essex	64,960.6	82,840.3	91,848.1	99,960.7	132,876.2	155,592.9	165,689.1	144,424.6	116,076.9	115,185.5	127,985.7	104,798.3	103,728.5	89,827.8
Huron	1,846.0	1,472.4	1,700.4	1,316.6	2,027.0	1,442.0	1,525.3	1,515.0	1,144.5	1,191.3	1,352.9	1,408.5	867	873.3
Kent	116,350.4	106,192.5	81,508.7	65,631.3	64,236.1	55,882.8	74,583.9	68,042.1	51,395.9	56,756.9	62,749.8	81,671.4	97,785	77,102.3
Lambton	36,023.8	35,207.8	40,430.5	36,596.6	37,379.0	34,803.9	31,188.2	28,977.5	35,245.1	33,617.2	35,038.9	34,161.1	32,946.4	36,648.8
Middlesex	1,534.2	1,697.0	1,380.6	822.3	605.1	567.5	595.4	310.5	340.1	229.9	251.5	14.0	52	265.3
Oxford	113.0	65.3	35.0	5.4	14.1		23.3	385.4	347.6	266.7	266.5	224.0	231.1	172.5
Total	243,698.5	247,824.5	235,615.1	222,320.3	254,370.1	263,873.4	288,009.1	257,394.5	217,098.7	211,106.7	238,166.7	232,306.3	244,845.8	214,167.9

Top Oil Producing Pools, 1992 - 2002

County	Pool Name	Geological Age	Oil Produced m^3
Essex	Mersea 6-23-VII	Ordovician	300,747
Kent	Romney 3-8-II	Ordovician	298,577
Essex	Rochester 1-17-II EBR	Ordovician	233,456
Essex	Mersea 3-6-V	Ordovician	176,597
Kent	Romney 6-13-III	Ordovician	163,702
Essex	Mersea 3-4-IV	Ordovician	137,559
Elgin	Rodney	Devonian	103,116
Essex	Mersea 4-240-STR	Ordovician	101,090
Kent	Romney 6-13-IV	Ordovician	99,802
Essex	Hillman	Ordovician	96,645
Essex	Rochester 7-17-IV EBR	Ordovician	88,057
Essex	Gosfield North 2-21-VI	Ordovician	78,272
Lambton	Petrolia	Devonian	75,255
Lambton	Corey East	Silurian Salina/Guelph	69,546
Lambton	Oil Springs	Devonian	61,970

Top Oil Producing Pools, 1992 - 2002

County	Pool Name	Geological Age	Oil Produced m^3
Essex	Romney 3-8-II	Ordovician	86,763
Kent	Romney 5-15-I	Ordovician	48,911
Essex	Gosfield North 2-21-VI	Ordovician	38,759
Essex	Mersea 3-6-V	Ordovician	35,771
Kent	Mersea 3-4-IV	Ordovician	31,665
Essex	Romney 6-13-III	Ordovician	21,350
Elgin	Mersea 6-23-VII	Ordovician	17,201
Essex	Petrolia	Devonian	14,273
Kent	Rochester 1-17-II EBR	Ordovician	13,308
Essex	Rodney	Devonian	12,497
Essex	Mersea 4-240-STR	Ordovician	11,429
Essex	Oil Springs	Devonian	11,223
Lambton	Rochester 7-17-IV EBR	Ordovician	10,410
Lambton	Corey East	Silurian Salina/Guelph	7,229
Lambton	Hillman	Ordovician	7,141

Ontario Petroleum Institute Membership Application

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Ontario Petroleum Institute Inc.
555 Southdale Road East
London, ON, N6E 1A2 Canada

I am applying for membership in the Ontario Petroleum Institute.

Please check appropriate member category below:

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- ☐ **Associate Non-Voting** *Indirectly interested in the oil, gas or gas storage industries* . . . . . . $150 plus 7% gst
- ☐ **Associate Non-Voting** *Academics, government employees and corporate support staff* . . . . $75 plus 7% gst
- ☐ **Student Non-Voting Member** *Full-time students at recognized educational institutions* . . . . $30 plus 7% gst
- ☐ **Retired Member** *Active or Associate Member who has retired from active practice or employment; is 55 years of age or older; who, with a combined total of years of age and years of membership as an Active or Associate Member, is not less than 70; and was a Member in good standing at the time of retirement* . . . . . . $35 plus 7% gst by special OPI resolution

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Name ______________________________

Title/Position ______________________________

Company ______________________________

Mailing Address ______________________________

City ______________ Prov./State ______________

Postal Code/Zip Code ______________ Country ______________

E-mail ______________________________

Phone ______________ Fax ______________

Membership Directory Category *please check one*

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- ☐ Consultant (Geological, Geophysical, Petroleum Eng.)
- ☐ Utility
- ☐ Educational
- ☐ Other (specify):

Enclosed is the sum of $____________ being payment of membership fees for the fiscal year starting September 1 and ending August 31. I agree to be governed by the By-Laws of the Ontario Petroleum Institute. GST#104001458

Signed ______________________________ Dated ______________________________