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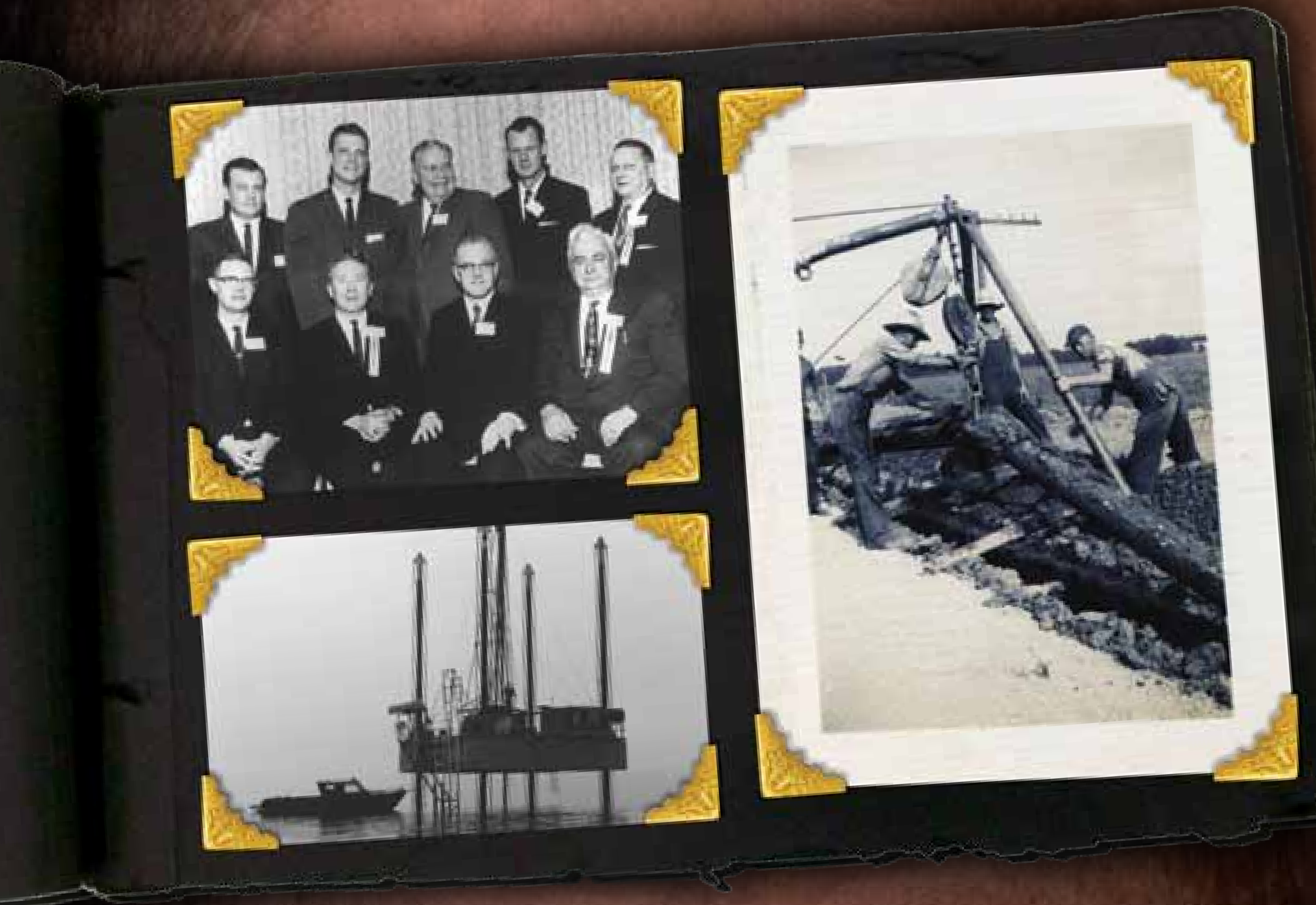

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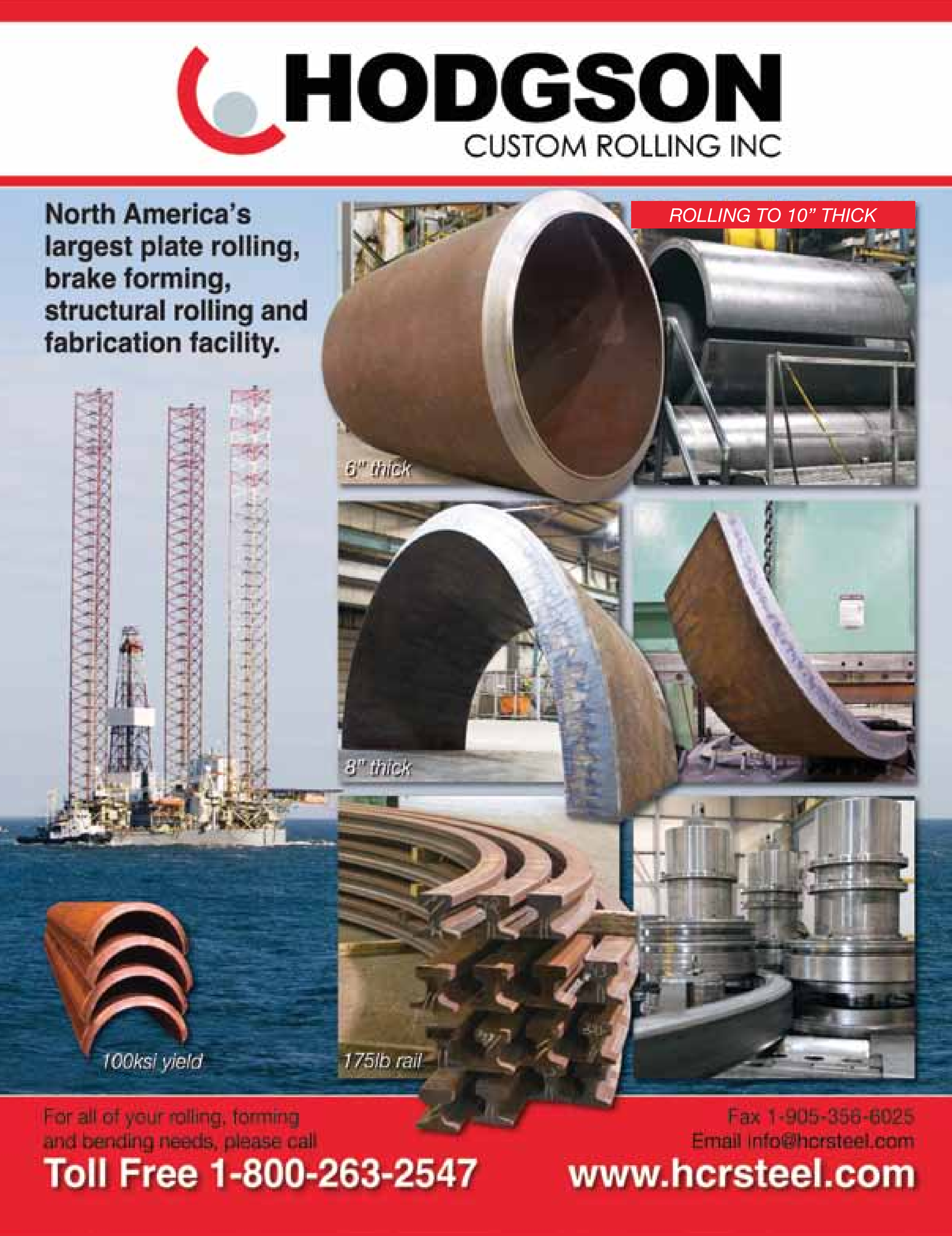
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PRESIDENT'S MESSAGE
IAN COLQUHOUN

Welcome to the Ontario Petroleum Institute's (OPI) *Ontario Oil & Gas Magazine*.

We are proud of our heritage at the OPI from the beginning with the Fairbanks family to the oil and gas producers of today who continue to develop the energy potential for Ontario. The dedicated people working in exploration and development, service and support companies throughout southwestern Ontario continue to inspire us. They remind us of the future potential in Ontario for collaborative growth in a dynamic energy marketplace, and of the enthusiasm that companies bring to the "patch."

OPI members are from industries that are committed to the exploration and development of oil and gas, hydrocarbon storage and solution mining that supports sustainable and responsible economic development. As a part of this commitment the OPI provides support to the industry through the services provided by the Ontario Oil, Gas & Salt Resources Library which is an integral resource centre for the research and development necessary to tap the potential for oil and gas in Ontario.

We continue to have a good working relationship and partnership with the Ontario Ministry of Natural Resources anchored by our mutual interest in the effective stewardship of the province's natural resources.

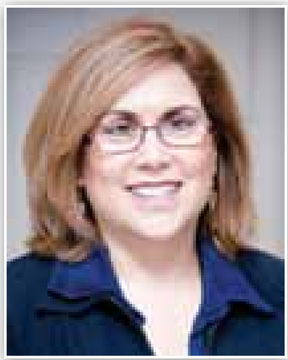
Times are also changing at the OPI. We welcome a new Executive Director, Hugh Moran who brings with him new energy and significant professional experience that will benefit the Ontario oil and gas industry.

We hope you enjoy Ontario Oil & Gas, and that reading the magazine will help you gain a greater understanding of the role of the oil and gas sector in Ontario.

Sincerely,

Ian Colquhoun
President, Ontario Petroleum Institute

CONGRATULATIONS *from* ONTARIO ENERGY ASSOCIATION



On behalf of the Ontario Energy Association's (OEA) Board of Directors and members, heartfelt congratulations to the Ontario Petroleum Institute (OPI) on the achievement their 50th Anniversary.

As the OEA embarks on our 10th anniversary, we look to the OPI as a model association and a distinguished example of longevity and quality service for its members.

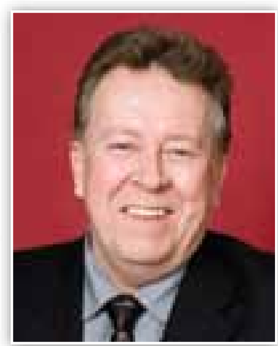
Once again, congratulations on 50 fantastic years!

Sincerely,

Elise Herzig
President and CEO, Ontario Energy Association

Ontario

A Message from the Minister of Natural Resources



I am pleased to have the opportunity to congratulate the members and board of directors of the Ontario Petroleum Institute as they celebrate the institute's 50th anniversary. I would also like to share my best wishes with the readers of *Ontario Oil & Gas* – an important source of information on industry events, issues and opportunities.

For the past half-century, the Ontario Petroleum Institute has done an outstanding job of advocating for the province's exploration and production industry, natural gas storage industry, cavern storage industry and salt solution mining industry. The institute has also been a valued partner of the Ministry of Natural Resources in working to ensure a safe and sustainable oil and gas industry by improving and updating operating standards and regulatory oversight.

It's been over 150 years since the first commercial crude oil was pumped out of the ground in southwestern Ontario, marking the birth of the modern oil industry. Since then, more than 90 million barrels of oil and 1.3 trillion cubic feet of natural gas have been produced in Ontario, using increasingly advanced technologies.

While the industries represented by the Ontario Petroleum Institute range from small family companies to large corporations, they are all part of the economic engine driving the province's economy and helping Ontario meet its domestic energy needs. Natural gas is playing a key role in the province's green energy strategy, and natural gas storage is growing to meet Ontario's energy demands for natural gas plants as coal is phased out. The salt solution mining industry continues to operate in both Windsor and Goderich, and cavern storage is attracting ongoing investment in Ontario, which is providing a competitive advantage to the province's oil and gas industry.

I look forward to further cooperation between the Ontario Petroleum Institute and the Ministry of Natural Resources as we work to ensure a sustainable oil and gas industry that contributes to a strong and healthy province.

Hon. Michael Gravelle
Minister of Natural Resources

PAST, PRESENT & FUTURE

OPI still delivers after all these years.

The Ontario Petroleum Institute (OPI) may be able to trace its roots back to an industry social club, but the real heart of the non-profit association can be attributed to the insightful, undertaking of three individuals. It was thanks to the work of these three "founding members" that the focus of the then Ontario Petroleum Club changed from being a mere social entity to a dedicated organization representative of all sectors of the oil and natural gas industry – one that would stand the test of time and come to earn the respect of both industry and government.

All for One and One for All

Back in the early 1960s, Hank O'Shea had already established himself as an oil industry insider. His buddies, Tim Rodger and Rollie Hall, were also working in the field in southern Ontario.

"We were good friends," explains O'Shea. "All three of us had spent time out west. Nobody out there knew about the Ontario industry – and Ontario was where it all began. We felt there was a real need for an organization here in Ontario that would align all sectors of the oil industry and, at the same time, raise the profile of the industry."

The three friends got together and decided to change the existing organization that was dedicated solely to social activities. The Ontario Petroleum Club had been in existence for only a couple years when the three friends joined and, at the next annual general meeting, discreetly got themselves and six new members voted onto the 12-seat Board of Directors.

"It was an interesting operation," states O'Shea. "Our guys were a fix from the start. They knew we wanted to take over the club and were all for it."

The year was 1962, and the Ontario Petroleum Club officially became the Ontario Petroleum Institute. Its new mandate – "to broaden industry representation and raise the profile of the Ontario oil industry." The change had been a success.

The Better Way

One of the first objectives of the new association was the creation of an annual technical conference. To help raise awareness, it was important to attract a large following of industry personnel.

"During that first conference, we had a number of people from western Canada," comments O'Shea. "We persuaded some of them to be official speakers."

O'Shea was voted in as president that first year, and did a lot to help form the foundation of OPI. Although he was asked to serve a second term, he respectfully declined, citing the need for change as critical to OPI's ongoing success.

"The industry was quite active at the time," says O'Shea. "We drilled about 200 holes a year."

Word of OPI and its new mandate soon spread and within a few years, the association had garnered broad representation and support from the industry, from explorers to producers, contractors, geologists, engineers, consultants – and more.

Within a couple of years, OPI was being asked by the provincial government to provide input into new regulations.

"There has been a lot of enjoyment over the years," recalls O'Shea. "But I would say that the more memorable moments were with the first conference we ever held. It was a milestone in a way. It brought a certain validation to the organization."

Although O'Shea is no longer active in the industry (at age 89, he has since retired), he does continue to stay current through his son, Kieran "known as Kerry," who is an industry environmentalist with Dillon Consulting Limited and a current member of the OPI Board of Directors.

"Our association is similar to a four-legged chair," explains Van Overberghe, who cites these four legs as representing exploration and production, natural gas storage, solutions mining and cavern storage.

"We helped put the industry on the map," states O'Shea. "We wanted to sell the oil industry to Canada. And we did achieve that success to a large extent."

Of course, it wouldn't have been possible without the underhanded, unassuming work of three close friends who were brought together in their single-minded mission to change the course of history.

"We weren't surprised that we were able to do what we did," concludes O'Shea. "We were good salespeople and the industry was looking for a voice. Every industry needs one. We just happened to be there at the right time."

An Evolution

Since O'Shea and his friends put OPI on the map so to speak, the association has changed. The 60 to 70 members of 1962 have grown to 300+. Revenues continue to be generated through membership sales and industry activities. And, despite the fact that the Ontario oil industry has dwindled significantly since its humble beginnings, OPI's membership numbers have held their own.

"Having seen the consolidation that has taken place in this industry over the past few years, we're very happy with our membership numbers," states Joe Van Overberghe, who has served as executive director of OPI for the last eight years.

"The primary role of OPI has evolved. We've become a bit more of a government relations organization and a bit of public relations as well."

Of course, the social aspect that founded the association has also remained. The annual conference continues to draw a minimum of 200+ attendees and continues to provide good networking opportunities for business and industry. Every other year, the OPI annual conference partners with the conference of its sister organization, the Independent Oil and Gas Association of New York, for better networking and educational opportunities for members on both sides of the border.

That being said, the areas represented by OPI members haven't changed much.

"Our association is similar to a four-legged chair," explains Van Overberghe, who cites these four legs as representing exploration and production, natural gas storage, solutions mining and cavern storage. "All of these industries are mature industries."

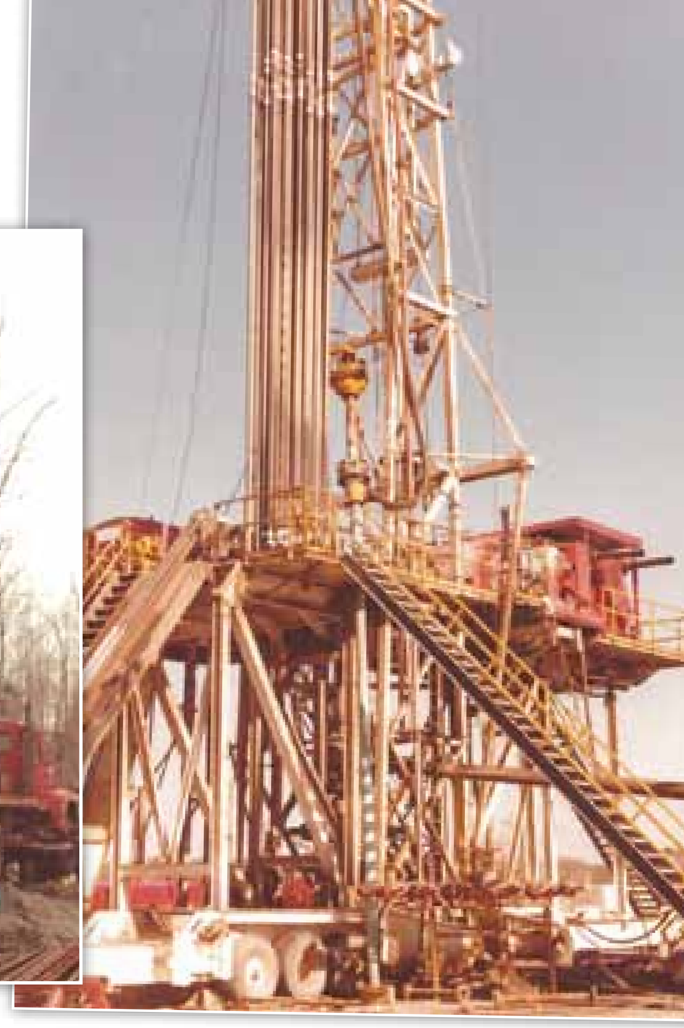
Other social activities organized by OPI include an annual golf tournament, industry meetings and a curling bonspiel (re-introduced this year after a few years on hiatus).

"The social aspect is still a big part of OPI," states Van Overberghe. "I think it always will be."

Van Overberghe defines OPI's current role as being as significant as it has been in past, adding the caveat that it is significant in a different way.

"We've evolved into more of a lobbyist organization," he states. "We've never had that role in the past."

Van Overberghe himself officially became a lobbyist two years ago.



"We're also have more of a role with other industry groups and organizations," he adds, suggesting that the association has become more representative as a result. "OPI is more connected nationally than it ever has been."

Icing on the Cake

In addition to continuing to speak on behalf of the Ontario oil industry, OPI has also done its share in promoting the industry. Milestone events, as identified by Van Overberghe, include: the fourth edition of its magazine, a key vehicle that aids in marketing the industry; becoming more in tune with industry regulations, specifically as they relate to the environment and the increased pressure stemming from this field; and the ongoing quiet promotion of a responsible and significant industry.

There's also the educational aspect, with this year being the first that OPI has partnered with a university to provide financial and resource support. This year saw OPI working with Western University for its recently introduced "Petroleum Geology" program.

On the other side of the coin, Van Overberghe is the first to admit that there are some significant challenges ahead for OPI. The largest of these he sees is to increase drilling in the province by way of creating an environment that is more socially and financially compelling.

"The oil and gas industry has been here in Ontario for 150 years now," states Van Overberghe. "We're lucky in that it's more acceptable in Ontario than in other areas of the country. And, we're fortunate that our landowners are our industry stakeholders. We're a small industry but we've managed to maintain the rhythm for all of these years. We just have to focus on ways to keep that rhythm going well into the future."

A Look Ahead

As to where Van Overberghe hopes to see the Ontario oil and gas industry in five to 10 years from now, he is quick to reply.

"The reality is that our membership numbers will be about the same as what they are now," he concludes. "What we would like to see is our members drilling more. We'd also like to see the many companies that are currently using our library to access data to actually come out and set up business in southern Ontario."

That library to which Van Overberghe refers is the Oil, Gas & Salt Library (OGSRL), a true fount of information that contains everything about the collection, generation and distribution of information on the subsurface geology, petroleum and salt resources of Ontario. It's an extremely useful industry tool, as well as historic minder, of everything important to the once bountiful oil and gas industry in southern Ontario. And, it may very well hold the key for future exploration that can resurrect the industry to the glory days of its past. ■

Centennial CELEBRATION

Union Gas celebrates over 100 years of serving customers and communities.

Over the past century, Union Gas has built a tremendous reputation for safe, reliable and affordable service to their now nearly 1.4 million customers. And, thanks to the generous spirit of their dedicated employees, they are also recognized as a long-standing community partner, supporting local schools, charities and non-profit organizations large and small in the more than 400 communities where they live and work.

Union Natural Gas Company of Canada was founded in 1911 through the amalgamation of three southern Ontario local gas distribution companies – Volcanic Oil and Gas Company, United Fuel Supply and Ridgetown Fuel Supply – all who had been rivals until then. It was an interesting time to be founding what would become a long-standing company.

In 1911, the entire population of Canada was just over seven million, the average life expectancy was 52 years, less than one per cent of families had a car and fewer than eight per cent of Canadians had a telephone. Natural gas pipelines were built of wood, natural gas was used mostly for lighting and cooking and the cost of heating a home with natural gas was about $4 a month.

Originally headquartered in Niagara Falls, Union Gas moved its head office to Chatham in 1918 to be closer to the centre of Ontario gas production. During the 1920s, Union expanded its operations into Sarnia, Wallaceburg and Windsor. From 1930 to 1960, Union

continued to expand its operations throughout southwestern Ontario, adding the cities of London, Stratford, Waterloo, Guelph and Brantford.

Now, it would be an understatement to say that a lot has changed since those days. In the three decades following their founding, the oil and gas industries in North America experienced tremendous growth, driven by the introduction of mass-produced automobiles, the movement of the population to urban centres in search of work and World War II, during which natural gas was used in camps, barracks and military hospitals.

In southwestern Ontario, the Union Gas distribution system was also expanding rapidly and by the early 1940s, local gas supplies had become scarce as existing production wells ran empty. Necessity being the mother of invention, Union Gas' first full-time geologist Dr. Evans, and Chief Engineer, R. L. Bevan, proposed to convert depleted underground gas production wells into storage pools to hold gas in reserve for peak cold weather demands. The idea was tested, and in 1942, Union Gas began feeding gas into two depleted storage pools at Dawn, southeast of Sarnia, Ontario.

This proved to be one of those memorable milestones for Union Gas, as it launched the company's diversification into the gas storage and transmission business.

Using Dawn for storage wasn't just significant for Union Gas, it changed the industry too, opening the door to transporting natural gas from the U.S. and western Canada into Ontario.

Two years later in 1944, Union Gas signed its first long-term contract with the Panhandle Eastern Pipe Line Company to import Texas gas into Ontario. With that contract, Union Gas began a productive 67-year relationship with Panhandle.

From that point forward, the pipeline interconnects to the Dawn area continued to grow, as did Union's own storage and transmission capacity. In 1946, two pipelines were built across the Detroit River connecting Dawn with Panhandle Eastern Pipe Line Company storage in Michigan. And, the following year, Union Gas began to store U.S. gas at Dawn for the first time.

In 1957, Union Gas finished building their first transmission pipeline, the 142-mile long, 26-inch diameter Trafalgar Line, connecting the Dawn facility to TransCanada Pipelines and Enbridge Gas, a distribution company that serves Toronto. In 1959, Union Gas extended its system north to Owen Sound. That same year, the first deliveries of Western Canadian Gas were received by Union Gas for storage and use by our customers.

Nineteen sixty-seven was another great year for connections. The TransCanada Great Lakes Pipeline connected to the Dawn facility, and Two years later, in 1969, ANR/Enbridge Pipeline connected to Dawn.

Quickly moving into the 80s, 1985 was a banner year. Union Gas became the wholly owned subsidiary of a newly created parent company, Union Enterprises Ltd. and in April, a significant milestone in Union Gas's history occured when the 500-thousandth customer was added.

On October 31, 1985, the Agreement on National Gas Markets and Pricing – otherwise known as the Halloween Agreement – eliminated the regulation of gas commodity prices in Canada, and established a more flexible, market-oriented gas price system. Large industrial natural gas consumers in Canada could now purchase their gas supplies at a negotiated price directly from producers. The development of the direct purchase market introduced new players, including gas agents, brokers and marketers. Union Gas played an active role in facilitating the very first direct purchase arrangement in Canada with CIL in Courtright, Ontario. Nova Chemicals Canada and LANXESS (and their predecessor companies Polysar and Bayer), followed just a few weeks later and are also among the first direct purchase customers in Canada.

Quickly moving into the 80s, 1985 was a banner year. Union Gas became the wholly owned subsidiary of a newly created parent company, Union Enterprises Ltd. and in April, a significant milestone in Union Gas's history occured when the 500-thousandth customer was added.

With deregulation of the natural gas market, the seeds of the Storage and Transmission market as we know it today were planted. A market that has continued to evolve, providing gas consumers with an ever-increasing degree of choice and flexibility.

In 1986, Unicorp Canada Corporation became the controlling shareholder of Union's parent, but just six years later, in 1992, Unicorp sold Union Gas to Westcoast Energy Inc. of Vancouver B.C.

In 1994 Union Gas entered into a shared services operating arrangement with sister company and fellow Westcoast subsidiary, Centra Gas Ontario, a natural gas distribution utility serving about 225,000 customers along the TransCanada Pipeline, across northern and eastern Ontario.

On January 1, 1998, Union Gas and Centra Gas Ontario were amalgamated, under the name of Union Gas Limited, a company now serving over a million customers from the Manitoba border to the Quebec border, and the industrial heartland of Southwestern Ontario from Windsor to just west of Toronto. Today, with about 2,200 employees working in communities across Ontario, Union Gas is a major employer in the province.

On January 1, 1999, Union Gas transferred its retail merchandise programs, including equipment sales, rentals, financing and appliance service programs, to an unregulated energy services affiliate, Union Energy. Union Gas continued to provide safe, reliable and economical delivery of natural gas to customers. In an increasingly competitive energy marketplace, the company has concentrated its efforts on providing high-value energy delivery services to meet the changing needs of customers, including energy retail marketers.

Over several years, Union Gas changed company hands – Duke Energy's March 2002 purchase of Westcoast Energy, meant Union Gas became a Duke Energy company, then on January 1, 2007, Duke Energy spun-off its natural gas business, including Union Gas, into a new publicly traded company named Spectra Energy Corp.

But, all along Union continued to enjoy strong growth and distribution, transmission and storage facilities expanded greatly to meet growing customer demand. Assets increased ten-fold from $400 million in 1975 to over $5.6 billion in 2011.

Over the past century, Union Gas has grown from a small local distribution company in southwestern Ontario into one of North America's premier natural gas storage, transmission and distribution companies. And their success has shared with their customers, suppliers and energy industry partners. ■

A Piece of HISTORY

Four generations and still going strong, the tradition of Fairbank Oil continues.

BY MELANIE FRANNER

When John Henry Fairbank agreed to take on a surveyor job in Oil Springs, Ontario, way back in March 1861, little did he know that it would be the start of a long and industrious journey that would eventually see him become the largest oil producer in Canada, employing some 400 people in Petrolia and the surrounding area. His was a life marked by hard work and good fortune, and when John Henry died in 1914 at the ripe old age of 83, he would leave behind a legacy of oil that would be picked up and passed on from father to son for three more generations.

Today, John Henry's great grandson, Charles Oliver Fairbank III, or "Charlie" as he is commonly known, presides over Fairbank Oil. True, the company no longer can claim to be the largest oil producer in the country, but it can lay claim to being a National Historic Site. It also remains a working oil field, producing 24,000 barrels each year using the same 19th century technology of the pioneers. Celebrating its 150th anniversary in 2011, it is the family that has been producing oil longer than anyone in the world. It has also been supplying Imperial Oil with crude since 1880, the year Imperial Oil was created in London, Ontario.

The Road Less Travelled

John Henry Fairbank (J.H.) was born in Rouse's Point, New York in 1831. When he was 22, he decided to try to better his fortune by moving to Canada. It was while in Niagara Falls, Ontario, that he met and later married Canadian Edna Crysler. After unsuccessfully trying his hand at farming, J.H. accepted a surveying assignment that took him to Oil Springs. While there, he got caught up in the oil fever, which was triggered in 1858 when James Miller Williams dug a well, refined the crude and began marketing his lamp oil. It was the birth of the modern oil industry and the oil rush began.

J.H. began his remarkable journey with the lease of a half-acre lot. The year was 1861. He christened his first oil well 'Old Fairbank' and he would run the well until 1865 before selling it and moving 12 kilometres north to Petrolia, where some oil finds had been reported. It was while running 'Old Fairbank' that J.H. developed the jerker line system, which used one engine to run 20 wells, as opposed to needing a single steam engine for each well. The new system proved to

be a huge success and was quickly adopted throughout the area. It continues to be used at Fairbank Oil today.

Over time, J.H. would branch out into other business ventures. He entered into various partnerships that eventually brought under his helm a dry goods/hardware store (which would become the largest hardware store west of Toronto), a bank (which would become one of Canada's last private banks), a refinery and a mortgage centre. He also continued to buy up the land and add to his growing number of oil wells.

As the oil continued to flow in Petrolia, J.H. assumed more and more of a leadership role in society. He was the president and general manager of the Home Oil refinery for eight years. He served three terms as the Chief of the Petrolia Fire Brigade and he served as president of the Crown Savings and Loan mortgage company for 30 years.

Throughout all of this, J.H. continued to acquire farmland, forests and real estate. In the early 1880s, he had added a 120-acre oil field property to his Oil Springs holdings. This property became Fairbank Oil and continues to pump oil to this day. The acquisition of adjacent land a few years later would bring J.H.'s total land holdings to 350 acres.

J.H. also entered politics. He was elected the Liberal Member of Parliament for East Lambton in 1882 and would retain that position until 1887.

By 1891, J.H. had put the finishing touches on his mansion, the largest in Lambton County, replete with a ballroom. He continued to add to his growing list of enterprises by purchasing Stevenson Boiler Works. He also opted to back the Petrolia Wagon Works – a move that would end up costing the Fairbanks a third of their fortune when the company went bankrupt in 1920, six years after J.H.'s death in 1914.

The Next Generation

Charles Oliver Fairbank, the son of J.H., took over the reins of the company in 1912. He was 54 years old at the time. Although Charles learned a lot about the oil business from his father, his career took a different path until his brother died in 1881. Prior to that, Charles studied at Helmuth College in London, Ontario, before enrolling in the Royal Canadian Military College in Kingston. He subsequently took on more military training in England and eventually, earned his medical degree at Columbia University in New York in 1891.

Upon his return to Petrolia, Charles teamed up with a partner to discover new oil wells in Bothwell, a town located 30 kilometres southeast of Petrolia. Charles was also the first (and only) of the Fairbanks to discover oil outside of Canada. He and his partner bought land in Elk Hills, California, and leased the rights to Standard Oil. It proved to be a huge success – so much so that the U.S. government eventually took back the land.

One month after the death of his father, Charles struck Canada's

"I didn't know of the legacy of Fairbank Oil the first time I met Charlie," explains McGee, who adds that she slowly came to realize the significance of the family in Canada's oil history. "It came on me by degrees."

first gas gusher in Oil Springs. By August of 1914, World War I had begun and Charles resumed his military career and despite being 56, he fought at The Battle of the Somme. He continued to oversee the family business until he died of Bright's Disease at the age of 66.

Carrying on the Tradition

Like his father, Charles Oliver Fairbank II never really expected to run the family business. He was 21 when his father died in 1925, and the business was passed on to him and his three brothers, as well as his father's sister and her children. But, circumstances changed things. Charles' older brother died shortly thereafter and Charles became the eldest son. He had studied at Ridley College in St. Catharines and earned a petroleum engineering degree from the University of California. In 1932, at his mother's behest, Charles returned to Petrolia to take over the family business.

Like his grandfather, Charles did a stint in politics, becoming the provincial Liberal Member of Parliament from 1938 to 1942.

Charles was also responsible for bringing the Fairbank Oil business under his sole ownership. He accomplished this in 1973. His son, Charlie, then purchased the property and took over the mortgage. This allowed Charles to focus solely on the hardware store – a business that had carried on from the time of J.H. Charles died in 1982 at the age of 77.

The Tradition Continues

With many of the Fairbank's fortunes being at the mercy of the ebb and flow of the oil market and its fluctuating prices, Charles Oliver Fairbank III (a.k.a Charlie) took his father's advice and sought out a career independent of the oil fields – just in case he needed something to fall back upon. He attained a biology degree from the University of Western Ontario and a teaching degree from Queen's University. But, despite this calculated move, Charlie's love of oil soon drew him back to Fairbank Oil.

In August 1973, just before the Arab Oil Embargo, Fairbank Oil had 70 producing wells and 70 idle wells spread over 350 acres in Oil Springs. The oil embargo's impact was immediate and sent prices skyrocketing. Being an oil producer was suddenly a viable business – until the crash of 1986. To counter the collapse of oil prices, Charlie bought adjacent fields – adding 250 acres and 180 producing oil wells.

It had been Charlie who encouraged his father to buy out the other members of the family and become the sole owner of the company – which was accomplished in 1973. Charlie's subsequent purchase of the family business resulted in the official name change to Charles Fairbank Oil Properties Ltd.

What's in a Name

Today, Charlie continues to run the company and his wife, Patricia McGee, is a journalist who handles the communications end of the business. The two met through a mutual friend and have been together since 1990.

"I didn't know of the legacy of Fairbank Oil the first time I met Charlie," explains McGee, who adds that she slowly came to realize the significance of the family in Canada's oil history. "It came on me by degrees."

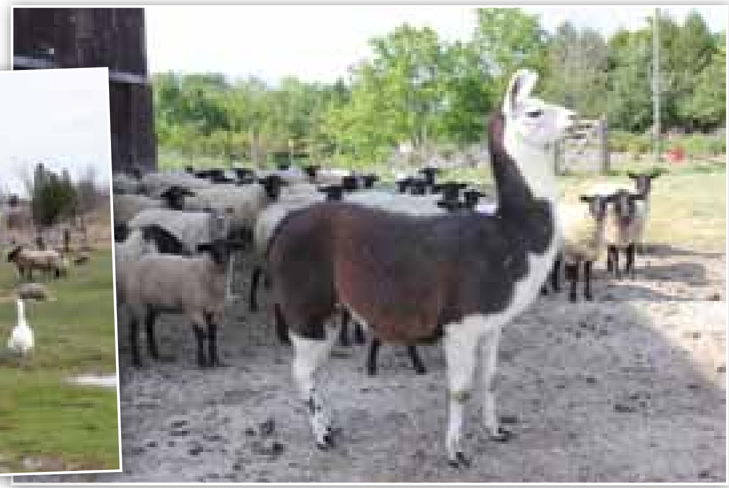
Charlie and Patricia – along with their two sons young Charlie and Alex – continue to live on the Fairbank property in Oil Springs in the original foreman's farmhouse that was built in 1888. The house has since been expanded and upgraded to accommodate green energy – a technology that both Charlie and Patricia strongly support.

"Many people think of oil as being environmentally destructive," comments McGee. "People who come here continue to be surprised. We have wetlands, woodlands and wildlife. Wild turkeys strut around here and there are guinea hens and geese too. We have llamas and keep over 100 sheep. We use the sheep manure as organic fertilizer on our gardens. We also have over half a million honeybees on the property. Yes, we produce crude oil but we also believe oil is a precious resource that we have to use carefully."

Although Charlie continues to run the family business, he and his wife are committed to educating people on the history of Canada's oil industry and of the vital role that Ontario's Oil Heritage District played in this history.

"Charlie wants people to know that the modern oil industry began here in Oil Springs, a year before the Americans," notes McGee. "We feel that people should know about this part of Canada's history, especially because energy is such an important factor in so many things today. There's a story to be told and we're working hard to tell it. Charlie gives speeches and tours all the time to a wide range of professionals, associations and the public."





Charlie's efforts to garner more attention for the oil heritage has not gone without recognition. In September 2011, he was inducted into The Canadian Petroleum Hall of Fame at a gala dinner in Calgary. In 2008, he received three special honours: The Ontario Lieutenant Governor's Award for Heritage; The Lifetime Achievement Award from the Petroleum History Society of Alberta; and The Samuel T. Pees Keeper of the Flame Award from the Petroleum History Institute in the U.S. Earlier, he was presented with the Queen's Golden Jubillee Award and the Canada 125 Medal.

An Artistic Telling

One of the ways that Charlie and McGee used to better illuminate this story is through art. In honour of the 150th anniversary of Fairbank Oil in 2011, the two commissioned one of Canada's most distinguished stained glass artists, Christopher Wallis, to create two stained glass windows depicting the oil-heritage history for Petrolia's beloved Victoria Hall. Work is underway for art installations along the nature trail and a wooden mechanical bullwheel is being added to the entrance of the Fairbank Oil property.

Charles and McGee have been busy in other artistic ways as well. In 1981, Charlie commissioned Anne Marsh Evans and Jim Evans to paint a barn mural depicting the early trademark of the hardware store. The following year saw the creation of the Chicken Coop mural by Ariel Lyons. In 1997, Charles had Renee Ethier paint an empty oil tank as Thomas the Tank Engine on the north side of Gum Bed Line for his two young sons. The two sons were also behind the painting of dinosaur faces on several pumpjacks, which was done by Sue Whiting in 1999.

The Driving Tour of Fairbank Oil features a series of life-sized sculptures showcasing different stages of oil production. It can be a self-guided tour or one can tune into the radio and hear the narrative accompanying each stop. Charlie commissioned metal sculptor Murray Watson to create the pieces. They include 16 men, four horses and one dog made out of metal. An additional six sculptures, including one of Charlie and of his father, can be seen on the private, specialized tour of the property.

"It started when I tore down a barn on the property," explains Charlie. "I had all of these wooden tank wagons sitting there. I decided it would make more sense if the wagons were presented in context so I spoke to a friend of mine, who happened to be an artist, and the idea came from there. It was very successful and the focus on art continued."

McGee has also been involved in the Fairbank Oil story. She wrote a new website in the fall of 2011, which provided an update to her 2004 book, entitled *The Story of Fairbank Oil*.

"I guess one of the greatest surprises for me since marrying into the Fairbank family is that I have become totally immersed in the history," states McGee. "I had no idea that I would become involved in the oil industry to the degree that I have or that I would write a book about it. It's not a local history story, nor a national story. It's a global story that deserves to be told."

A Nod to the Future

Although Charlie and McGee have two teenaged sons who may carry on the Fairbank Oil tradition, the boys' exact degree of involvement in the family business remains to be seen. At the moment, young Charlie is in his second year at Trent University in Peterborough and Alex is finishing Grade 10.

"We're going to have to wait and see," concludes McGee. "They're still very young. My husband, Charlie, was never raised to be in the oil business. He grew up in Petrolia and only came out to Oil Springs once a year to cut down the Christmas tree."

Charlie himself is quick to mention that his involvement in the oil fields came as a surprise.

"My father asked me if I wanted to get involved in the family business a number of times," he explains. "And I always said 'No'. Then in 1969, I must have been between jobs at the time, and I came back to help. Within four hours, I knew that this was where I wanted to be. I fell in love with the oil fields."

And, it is this love of the oil fields to which Charlie has since remained true.

"I don't want to be remembered for anything," he concludes. "It's the oil fields that are important. I want to preserve a piece of history and geography. This is a magical place that deserves to be remembered." ■

WORKING TOGETHER

Baker Hughes is partnering with operators in Ontario's oil and gas industry to deliver solutions

Baker Hughes is a well-known member of the Ontario oil and gas sector with a long history of providing a wide range of services from reservoir engineering, to specialty chemicals used in downstream applications. In fact, our history stretches back to almost as far as the oil and gas industry in Ontario.

Although Baker Hughes was formed in 1987, with the merger of Baker International and Hughes Tool Company, both companies were founded more than century ago. Prior to the merger, both companies conceived ground-breaking inventions that revolutionized the petroleum industry. In 1907, Reuben C. Baker developed a casing shoe that modernized cable tool drilling, while in 1909, Howard R. Hughes Sr. introduced the first roller cutter bit that dramatically improved the rotary drilling process. Over the ensuing decades, Baker International and Hughes Tool Company continued to lead the industry with innovative products in well completions, drilling tools and related services. Since those earliest advancements, we've never stopped searching for solutions to conquer the next frontier.

With offices in various locations across Ontario, backed up by a solid Canadian infrastructure, Baker Hughes offers a complete suite of expertise including reservoir consulting, drilling, formation evaluation, completions, pressure pumping and production products and services. Baker Hughes has a long, successful history assisting customers with well inspections, according to Gord MacKenzie, station manager and wireline engineer.

"Baker Hughes' cased-hole and open-hole wireline services offer fit-for-purpose technology, enabling us to solve the operational and evaluation needs of customers across Ontario. We know our customers," says MacKenzie, who started his career in the Southern Ontario oil patch in the early '90s, and in 2000 transferred to gain additional experience in other areas. He has worked offshore in eastern Canada, the North Sea and the Gulf of Mexico, as well as on land in north western Canada and in various parts of the United States including Alaska.

"Working in these other locations, I rarely see the same people again," he says.

However, MacKenzie's experience with the Ontario "oil patch" is comfortingly different, operating more like a close-knit family.

"It's a pleasure to know the majority of people when you arrive on location. When you know the people you are working with in an operation, people have the confidence to make suggestions and speak freely, which makes for a safer working environment," says MacKenzie.

Safety is a paramount concern for Baker Hughes. "Our focus on health and safety, along with ensuring the environment is also protected before considering rig time and service costs, has led to very safe working conditions with minimal environmental impact."

Baker Hughes' wireline experts, including MacKenzie and the other four staff working from the Sarnia office, have more than 80 combined years of knowledge and work experience. With Baker Hughes' complete range of downhole electric wireline services for every well environment, including cased-hole advanced formation evaluation, production and reservoir engineering and petrophysical and geophysical data-acquisition services, MacKenzie is confident he has the tools and expertise required to meet the needs of the Ontario oil patch.

Baker Hughes can minimize interventions and nonproductive time because our customers value our ability to efficiently and accurately evaluate well performance through our production logging services, explains MacKenzie.

He and his team can customize these services for optimal measurement of a wide range of production conditions, including vertical, highly deviated or horizontal wells, and also use them for a variety of well completion types, including open hole (barefoot), cased and perforated, gravel-packed or slotted-liner configurations.

"One of our primary objectives is to determine and quantify a well's production profile with the ultimate goal of increasing reservoir production and reducing downtime. Production logging allows us to evaluate production operations and diagnose potential problems

"The reach of Baker Hughes in supporting similar downstream sectors across the world means we have proven technology and products in pipeline, hydrocarbon processing and petrochemical industries that will help increase production, improve plant safety and equipment reliability," says McNairn.

like water or gas breakthrough, crossflow of thief zones and channeling – all in real time," he elaborates.

Production logging measurements are often combined with cased-hole reservoir evaluation services like pulsed-neutron logging. This combination provides saturation and production logging data for a complete well-performance evaluation. MacKenzie says the equipment performs in conditions ranging from simple single-phase production to complicated annular three-phase flow in a horizontal well completed with a slotted liner.

One area of well inspections that has experienced growth, according to MacKenzie, is well casing inspection. Since some of the wells are getting older, customers want to know beforehand about any potential problems. That's where Baker Hughes' Vertilog™ casing-inspection service, which uses magnetic flux-leakage measurements, can identify and quantify internal and external corrosion defects. This service, which relies on the overlapping arrays of flux-leakage sensors and discriminator sensors, offers full-circumferential inspection of the tubing or casing string. This process differentiates between metal-loss (corrosion) and metal-gain (hardware) features, and distinguishes between general corrosion and isolated pitting.

While the Vertilog system provides very good information, Baker Hughes' High-Resolution Vertilog™ (HRVRT™) system delivers even a higher resolution. The HRVRT service delivers the highest-resolution electromagnetic casing inspection in the industry. The system's 360-degree defect map accurately pinpoints the location, size and shape of a casing defect, whether internal or external. The advanced information and processing of the HRVRT data can save customers costly well repairs, mitigate production loss or delay well abandonment.

MacKenzie adds that all of his experiences and interactions throughout his career, including those with the OPI – which he says "acts as the hub to bring all the spokes together" – have provided him with one of the most enjoyable working environments he's experienced.

From Downhole to Downstream

According to Craig McNairn, business development manager in the Industrial Processes Portfolio, Baker Hughes has been working many years in the Sarnia area.

"The reach of Baker Hughes in supporting similar downstream sectors across the world means we have proven technology and products in pipeline, hydrocarbon processing and petrochemical industries that will help increase production, improve plant safety and equipment reliability," says McNairn.

Baker Hughes is well prepared to support hydrocarbon processing with environmentally friendly additives used to treat crude oils, as well as finished fuels.

When it comes to the specialty chemical needs of refiners, Baker Hughes has products for this activity as well.

"When a plant is doing a turn-around, they have come to trust the specialty cleaning chemicals we offer knowing that the product will give them repeatable results so they can get the job done safely and quickly," he expresses.

At Baker Hughes we are proud to be a long-term partner in a viable, active and important industry in the province of Ontario.

Congratulations OPI on 50 years of being a voice for the industry. ■

CROWN JEWEL

Corunna becomes prized asset for Provident Energy.

BY COLLEEN BIONDI

In its early days, Calgary-based Provident Energy's portfolio was heavily influenced by its oil and gas assets. Over the last decade, in its effort to focus its business direction and respond responsibly to market and analyst demands, it has changed course.

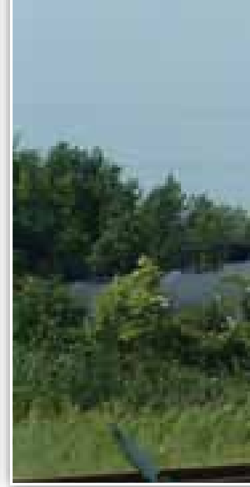
In 2003, the company bought a portion of the natural gas liquid (NGL) midstream business from Williams Energy and, in 2005, added EnCana's midstream business.

Today, it has sold off its entire oil and gas segment to become "the second largest midstream player in Canada," says Andrew Gruszecki, executive vice president of midstream business units. Assets now span from northeastern British Columbia to Sarnia, Ontario and Lynchburg, Virginia. Major facilities include the Redwater West System (north of Edmonton and containing one of the largest NGL rail yards in Canada) and the Empress East System (from Empress, Alberta and extending into eastern Canada). Offices in Calgary, Houston and Sarnia facilitate access to a wide range of viable North American markets.

This dividend-paying, public company's services include NGL extraction, fractionation, storage, transportation, logistics and marketing of its own product and the product of third parties. It currently has over 300 employees and functions within a corporate structure (moved from an income trust model early in 2011).

Strategic growth is a key component of the company's vision, adds Gruszecki. Last year the company developed new cavern storage at Redwater, acquired a trucking company in Saskatchewan and constructed an NGL terminal in Manitoba. The company is well positioned to develop further in the Montney and Appalachian natural gas plays, the Bakken oil play and the Alberta Oilsands.

Another Provident Energy location which is proving to be "a crown



"They decided to get out of the ethylene business in eastern Canada," says Mike Hantzsch, vice president of business development, and solicited bids for the facility. "We were the successful party and acquired the property in March 2010."

jewel with significant growth prospects" is Corunna, Ontario, a tiny town of just under 15,000 people located 15 minutes from Sarnia. The company already had fractionation presence in the community. Recently, it made another key acquisition – a storage and terminalling facility.

Previously owned by Dow Chemical Canada, the facility had been used to store petrochemical and derivative products converted from ethylene feedstock supplied from its Fort Saskatchewan facility via the Cochin Pipeline. But, when a repair to a pipeline leak resulted in lower operating pressures and reduced throughput, ethylene could no longer be transported to Cochin. In addition, when the global ethylene market provided debilitating competition, Dow made a big decision.

"They decided to get out of the ethylene business in eastern Canada," says Mike Hantzsch, vice president of business development, and solicited bids for the facility. "We were the successful party and acquired the property in March 2010."

The property is 1,100 aces in size. It has 12 million barrels of underground storage capacity -- five million are available for the storage of hydrocarbons like propane, butane and crude oil and seven million currently contain brine (in earlier times, Dow used to mine brine as a feedstock for the production of chlor alkali). The site is affectionately referred to as The Farm and 400 of its acres are actually leased to local farmers to grow corn and soybeans.

Dow had used the facility for its own proprietary use, explains Gruszecki. But Provident bought it as an "open access" site with a view to offer integrated, fee-based, logistical services to other companies. "It has great connectivity to facilities in the Sarnia area," he adds.

One of the unique aspects of this purchase was the fact it involved a union environment. "It was the first time Provident had a unionized labour force and had to negotiate a collective bargaining agreement," says Hantzsch. But the CEP Union was excellent to work with; there was a lot of respect and good will on both sides. "It was a great learning experience and was relatively painless."

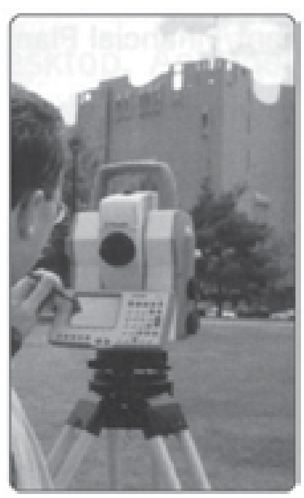
In addition, the town's citizens were pleased about the purchase as it represented great potential for renewed job growth, giving Corunna a much-needed, economic shot-in-the-arm after several troubling, recessionary years.

Provident has already spent $50 million to refurbish the complex, getting it up to safety and operational standards and providing a

full suite of services. And they are not finished. “It is going to require money but the analogy we use is that this could become equivalent to our Redwater facility,” says Gruszecki.

Provident will not only run this facility, but is committed to investing in the broader community as well. The company has been in talks with the mayor of Corunna, Steve Arnold, about ways it can become a valuable corporate citizen. To date, it has signed off on modernizing an historical museum in nearby Sombra, just south of Corunna, and there will be more projects on the books soon, says Hantzsch. “It is our civic responsibility.”

It is this focused, strategic and prudent vision along with a plan to work closely and respectfully with key petrochemical customers and community citizens which bodes well for Provident Energy’s ongoing success, says Gruszecki. "It is an exciting time to be in the energy infrastructure business.” ■



TAPPING INTO POTENTIAL FOR GROWTH

Ontario libraries offer a fountain of information on oil and gas history.

The Ontario oil and gas industry may be small compared to its western counterpart, but it's one well researched and well documented. And, by far, most of this information can be found in the Ontario Oil, Gas & Salt Resources Library (OGSRL), located in the southwestern city of London. The library specializes in the collection, generation and distribution of information on the subsurface geology, petroleum and salt resources of Ontario. It is home to rock samples from some 14,000 drillings, along with field reports outlining well history, construction, location, stratigraphy, oil, gas and water-bearing intervals. It also houses an ever-broadening collection of research reports and publications.

Today, the OGSRL has a 30+ member base, comprised of corporations and geological consultants and/or individuals.

"It's hard to put a value on something like this," explains Richard Ostrowski, facilities and program manager, OGSRL. "It's incredibly important. This is where companies come to get information. Otherwise, they would have to spend hundreds of thousands of dollars to build their own libraries."

An Industry Commitment

The OGSRL owes its beginnings to the late 1800s and early 1900s, when the Geological Survey of Canada began requesting voluntary submissions of drill cuttings and core from oil and gas wells drilled in Ontario and other parts of the country. This led to the creation of a core and sample processing, storage and study institution in Ottawa. In 1950, a similar facility was established in the city of Calgary and all samples from western Canada were sent to this location.

In 1971, the Petroleum Resource Laboratory (predecessor to the OGSRL) became the new home to all of the Ontario core and cuttings. The current building which houses the OGSRL was built in 1987 and in the following year, responsibility for the library facility was transferred to the Oil, Gas and Salt Resources Trust, a creation of the Ministry of Natural Resources. The Minister of Natural Resources then appointed the Ontario Oil, Gas & Salt Resources Corporation, a wholly owned subsidiary of the Ontario Petroleum

Institute, as the Trustee. This change marked a significant point in the history – and future – of the OGSRL.

"In 1998, the Ministry of Natural Resources wanted to discard our entire collection," explains Ostrowski, adding that it was meant as a cost-cutting measure at the time. "That's when the industry stepped in and took over management of the library."

Today, the OGSRL has a 30+ member base, comprised of corporations and geological consultants and/or individuals. Much of the cost of its day-to-day operation (which currently consists of two full-time employees, one contract employee and one part-time contract employee) is covered through these membership fees. Other funding comes from the cost of preparing and filing the required cuttings from drilled wells (at a fee of 90 cents per metre) and from preparing and filing the required core samples (at a fee of $10 – $30 per metre, depending if they arrive pre-cut or full diametre). All companies that drill wells licensed under the Oil, Gas and Salt Resources Act are required to collect cuttings samples of bedrock from the entire length of the drill hole at three-metre intervals and to deliver these samples to the OGSRL. The rest of the OGSRL's funding is derived from royalties paid out by every company that produces oil and gas in the province.

Moving Out of the Stone Age

According to Ostrowski, the primary role of the OGSRL is to provide data to the industry – be it the geophysical logs of historical or established wells, production data or anything in between. The facility's files and sample storage areas are available primarily on a self-serve basis during operating hours (Monday to Friday from 8 a.m. to 4:30 p.m.). However, staff is available to help if help is required. Although requests for information may be taken by phone, fax or email, the majority of current requests occur over the Internet.

As a result, the OGSRL has strived to meet the needs of its members over recent years by making sure its wealth of information is available online.

"I would estimate that about 75 per cent of our information is now available to our members online," explains Ostrowski, who adds that the employees have been busy scanning and digitizing this information since around the year 2000. "We should have the rest of our library online within the next two to four years."

In addition to making the library records accessible to members via the Internet, the OGSRL also adds value to its ever-growing wealth of information in other ways.

"Mistakes happen," states Ostrowski. "One of our roles is to use historical data to correct misinformation before it goes online."

Another area in which the OGSRL gets involved is research. A case in point is the Targeted Geoscience Initiative, which involved the OGSRL, the Ministry of Natural Resources and Ontario Geological Survey in a two-phase initiative known as the Southern Ontario Hydrocarbon Resource Evaluation and Regional Stratigraphic Synthesis. The project involved the hydrocarbon resource evaluation of the Ordovician Trenton-Black River hydrothermal dolomite play in southern Ontario and regional stratigraphic correlations. As to update the evaluation of Ontario's resources of oil and gas, which was completed by the Ontario Geological Survey in the early 1980s. The objective of the second phase of the project was to produce and publish an updated report based on Paper 67-2 of the Ontario Department of Energy and Resources Management. The work was completed in 2005.

"This was a fairly large project for us," explains Ostrowski, who adds that the work was completed to all party's satisfaction. "Everyone was happy with the results."

The OGSRL is currently working on a government Emergency Response project that will enhance the data available to inspectors so that the inspectors have a quicker means of responding while out in the field.

"Due to the generosity of our members, the government and our industry, we continue to receive support for data and publications development," states Ostrowski, who adds that as more and more of the OGSRL's data resources are transferred online, there will be more and more time and resources to pursue other research projects.

Supporting Future Growth

Of course, one of the most significant roles that the OGSRL has today is to help promote future growth within the Ontario oil and gas industry. Providing access to data is, of course, one way to accomplish this. And the OGSRL remains committed to doing just that. But an unstable global economy has played havoc on what was once a thriving industry.

"There has been only about six new wells drilled this year," states Ostrowski. "Five to 10 years ago, that number was closer to 80."

Despite this downturn, Ostrowski remains positive about the future – and about the potential for companies to find new resources.

If and when companies begin to tap into this as yet undiscovered wealth of oil and gas, the OGSRL will be at the ready to step in and help in any way it can. Comfortably housed in a 6,000 square-metre facility, the OGSRL is well positioned to support those companies and individuals who are looking to build upon the industry's strong history – and the 26,000 existing wells in Ontario – to create an even brighter and more profitable future.

A National Story

Another oil and gas institution with a strong story to tell is the Oil Museum of Canada (OMC). Opened in July 1960, in commemoration of the 100th anniversary of the digging of the first commercial oil well in North America, the OMC pays tribute to the area's long and strong history seeped in oil. Visitors to the museum, which is located in the Village of Oil Springs in Lambton County, get to view the site of Canada's first oil well, dug by James Miller Williams in 1858, or they can take a self-guided Oil Patch Driving tour (that tunes into their FM radio) past some of the adjacent oil wells that continue to produce oil to this day. The museum itself contains four galleries, indoor and outdoor exhibits, tours and some 3,000+ artifacts that help tell the history of what was once the nation's largest oil-producing area before 1900.

"On average, we get about 4,500 visitors a year," explains Connie Bell, supervisor, OMC, and a 22-year veteran of the institute. "We get a lot of local visitors, as well as quite a range of international visitors from around the world."

Preserving a Slice of History

Inside the two-storey building is an array of exhibits that contain a wealth of information and artifacts. This includes: the Theatre Room (where an introductory DVD explains the history of the area's oil production); a Main Gallery that explains the historical and geological side of oil; the Oil Springs Gallery that offers insight into the social history of the area; and the Foreign Drillers' Gallery, which is dedicated to the early oil men who helped shape the industry.

Exhibits located outside of the main building include: Power House, Jerker Lines, Oil Tanker Wagon, Holding Tanks, Langbank Post Office, Canadian Pole Drilling Rig, Blacksmith Shop, Three Pole Derricks, Gum Beds, Procar Tank Car, 1895 Oil Springs Railway Station, Natural Gas Industrial Building, Picnic Area – and the site of the first commercial oil well in North America.

Located nearby are several other significant must-see items, including Ontario's last Receiving Station, Cribbed Holding Tanks, Modern Holding Tanks, Jerker Lines, Historic Black Creek, the Shaw Gusher of 1862, Morningstar Holding Tank, the Fairbank Barn Mural, 1904 Morningstar Oil Producers property, the former Watson's Machine Shop building and the Plank Road to Sarnia.

"This is a national historic site," explains Bell. "It's the birthplace of the modern oil industry. The tools, technology and techniques developed in the Oil Heritage district of Lambton County are significant and helped to lay the foundation for the industry. Local drillers learned their

skills here in Lambton County and then travelled around the world with their expertise. These drillers were respectfully known as the Foreign Drillers and they were in high demand."

A Successful Operation

The OMC employs one full-time employee and three part-time employees. Funding is attained through the sales of items from the OMC gift shop, admissions and donations, as well as through a provincial grant and funding from the Corporation of the County of Lambton.

In addition to an array of international visitors, the OMC also attracts its share of students.

"We do get school tours, although we would like to see more take advantage of this national site," states Bell. "Our school tours span all grade levels, right into high school."

A special provincial grant received in 2008 helped mark the 150th anniversary of North America's first commercial oil well at the site and provided money to update the OMC exhibits.

"We were able to use the grant to upgrade museum exhibits and signage," explains Bell. "Today's generation is looking for bells and whistles. It's no longer enough to just provide a range of photographs and static displays. We used the money for a variety of different initiatives, including developing the FM radio driving tour, creating a new, introductory DVD, erecting a Foreign Drillers' tent exhibit inside the museum and tweaking a lot of the exhibits to better connect with our visitors."

As for the future of the OMC, Bell envisions a day when the museum moves beyond its current provincial and national designations.

"Our ultimate goal is to be designated a UNESCO World Heritage site," she concludes. "There are a lot of steps to be put into place along the way, but that's the ultimate goal." ■

BUILDING BRIDGES

Breaking down barriers between First Nations and industry

BY CHERYL CARDINAL, ACTING DIRECTOR, NATIONAL ENERGY BUSINESS CENTRE OF EXCELLENCE

The National Energy Business Centre of Excellence is a program of the Indian Resource Council that was officially started in 2008. The Centre of Excellence has been an evolving organization that creates programs to suit the needs of First Nations and the oil and gas sector.

In January 2012, the National Energy Business Centre of Excellence launched our new water module in our Introduction to Oil and Gas Development training. This module was designed to educate First Nations on ownership and jurisdiction of water and create a better understanding around Shale gas development, fracing and possible effects on water. This module was created after consulting fracing companies, various oil and gas companies and First Nations leadership to ensure that an un-biased approach was taken. The issue of water use by the industry has been at the forefront of discussions surrounding oil and gas development.

In December 2011, in the Introduction to Oil and Gas Development training, there was a component where successful First Nations have been brought in to discuss a "how to" towards development. The models that each First Nations hold are specific to their Nation and the Centre of Excellence recognizes cannot be transplanted from one Nation to another, but the lessons and tools of "how to" can. The goal of training using successful First Nations is to give other First Nations an opportunity to learn and move forward towards successful development.

In September 2011, the Centre of Excellence also completed its GAP analysis with the oil and gas industry to understand the gaps that exist with First Nations. This will assist the centre in directing and evolving services that best fit the needs of the industry to create meaningful working relationships with First Nations nationally.

Over the last four years, the National Energy Business Centre has been working diligently to maintain a national mandate and include First Nations from the various regions in Canada.

Background – Indian Resource Council

The Indian Resource Council was founded in 1987 by First Nations Chiefs representing oil and gas producing First Nations. The Indian Resource Council was to ensure that the federal government under Indian Oil and Gas Canada (IOGC) fulfilled their fiduciary and statutory obligations related to the management of oil and gas resources on First Nations lands and to further First Nations initiatives to manage and control their own oil and gas resources. IOGC is a Special Operating Agency under the authority of the Department of Indian and Northern Affairs Canada.

The Chiefs wanted to establish an organization that worked alongside IOGC as a "watchdog" to ensure that IOGC fulfilled its mandate, especially those mandates that pertained to their fiduciary and trustee responsibilities.

The Indian Resource Council has been involved in various developments. Recently, the Indian Resource Council has been assisting the regulatory changes for the Indian Oil and Gas Act (that has not been changed since 1970s). The Joint Technical Committee 1 is involved in this work.

The Joint Technical Committee 2 has recruited various First Nation people who are involved in the IRC Board as leaders, business leaders and from those communities that have set up successful business ventures on their lands. This committee serves in an advisory capacity to the strategic direction of the National Energy Business Centre of Excellence.

The National Energy Business Centre of Excellence was started as a means for First Nations to receive business development assistance in oil and gas development. The Indian Resource Council conducted a national "First Nations Business Development Needs and Priorities" survey and compiled a report on its findings. All First Nations expressed a strong will to succeed and develop their resources to benefit their communities, but difficulties experienced in trying to move forward towards development. Each First Nation is at different stages of development whether they have a longer history with oil and gas activity or whether they are just starting out. Each approach that many First Nations take has different requirements and this is where the National Energy Business Centre of Excellence has created services to better assist First Nations in gaining economic success.

Services of the National Energy Business Centre of Excellence – First Nations

There were four main service areas that were developed as a result of the "First Nations Business Development Needs and Priorities." These areas are Business Information, Business and Technical Expertise, Capacity Enhancement and Networking.

The GAP analysis conducted with First Nations was completed back in 2008, and was the creation of the centre. Through our business and technical expertise, our analysis with First Nations found that they lacked the technical knowledge and the dollars to get involved. This is why the Centre of Excellence created a program that provides financial assistance for the "initial stages" of development. It is important to understand the need of each First Nation varies. The Business Centre has provided a variety of assistance to various First Nations. For business reasons, the names of the First Nations are not disclosed but the type of assistance that they receive is. First Nations have received assistance with feasibility studies, abandoned wells, joint venture expertise and valuation of land to name a few. Each area of assistance is tailored to the First Nation interested in developing their resources.

The Centre of Excellence developed a workshop "Introduction to Oil and Gas Development" designed to enhance First Nations capacity in understanding the oil and gas industry. This service has been delivered six times across Canada with a variety of First Nations communities and organizations. This service was developed in modules to adapt to needs of the First Nations.

It's important to realize there are many opportunities where First Nations have been getting involved. The networking function of the National Energy Business Centre of Excellence creates many opportunities for networking for First Nations with other First Nations, federal government and oil and gas industry.

Services of the National Energy Business Centre of Excellence – Oil and Gas Industry

The same four core service areas exist for the oil and gas sector that exist for First Nations. These four service areas are: Business Information, Business and Technical Expertise, Capacity Enhancement and Networking.

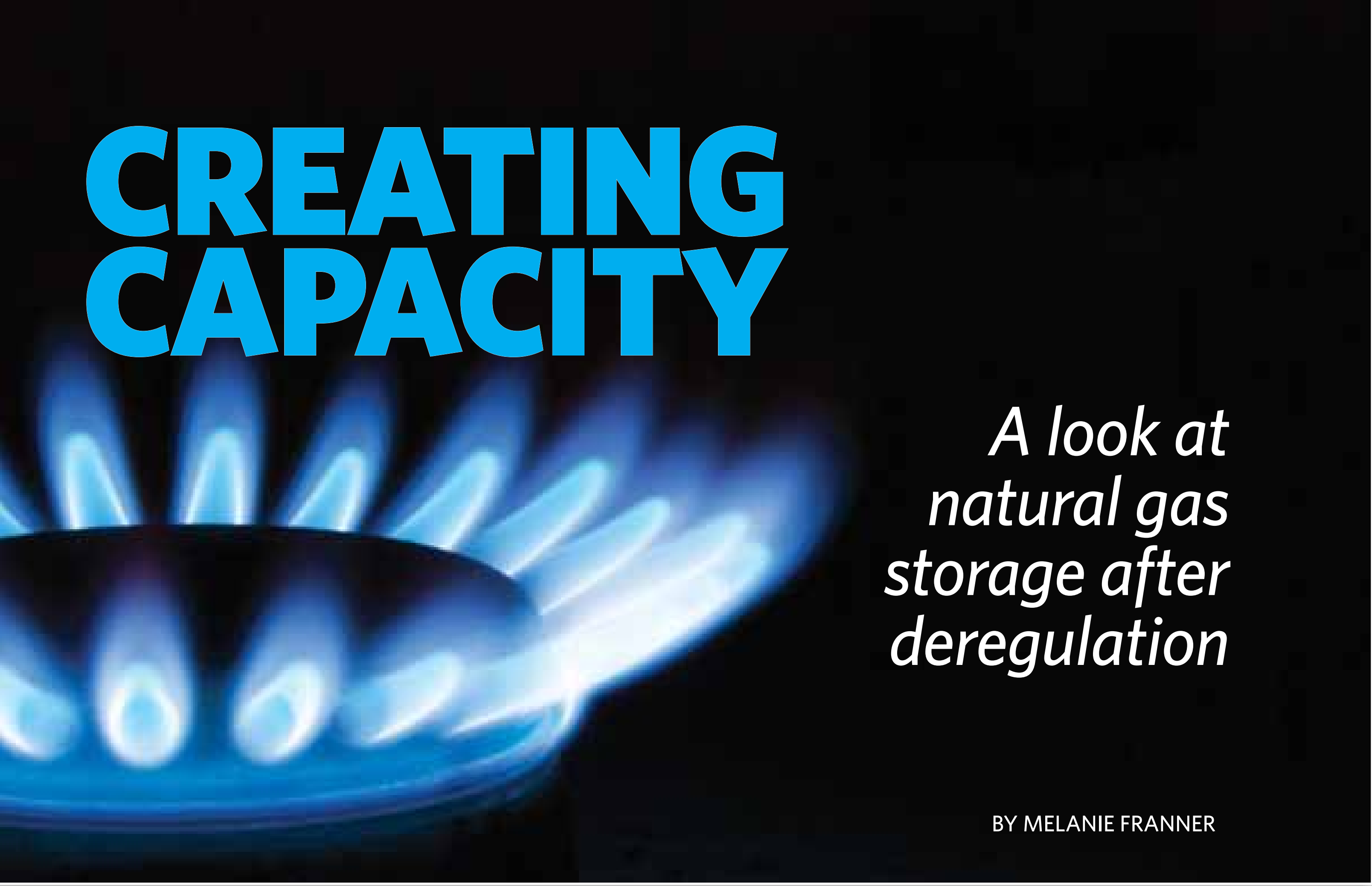
These areas are still under development, but major strides have been taken with those companies that have engaged the Centre of Excellence towards meaningful relationships with First Nations.

The National Energy Business Centre of Excellence has improved these relationships by assisting some oil and gas companies. One particular client of the Business Centre had an issue working with a group of Nations. Within this area, there were five First Nations that were being consulted with. Of the five, four had no issues with the development and one was holding back. Break-up was coming fast and if this nation did not give consent then this company was set to lose millions of dollars and would cause a delay in their project. The Centre of Excellence provided assistance to how to best deal with the situation. In this particular situation, communication was key to move the project forward.

The National Energy Business Centre of Excellence, in partnership with our parent company the Indian Resource Council, organized "Chief to Chief meetings" where it brought together First Nations leaders and oil and gas executives. These meetings were to bring together key initiatives and have frank discussions with the two groups to understand issues surrounding involvement in working together.

The National Energy Business Centre of Excellence has been working to improve good working relationships with First Nations and the oil and gas industry. Improving these economic opportunities and having greater First Nations participation in the oil and gas industry will lead to a stronger Canadian economy for all.

For more information about the National Energy Business Centre of Excellence: please visit our website at www.nebce.com or phone at (403) 252-1702. ■



CREATING CAPACITY

A look at natural gas storage after deregulation

BY MELANIE FRANNER

The Ontario Energy Board's (OEB) 2006 decision to deregulate non-utility natural gas storage in the province has opened the door to a subsequent boom in the market. Several major players announced development of new storage as a direct result of the decision. Among these are the likes of Union Gas, Altagas, Enbridge and Market Hub Partners Canada. Additional activity has also taken place with smaller, independent firms, which are opting to partner up with the larger industry giants or choosing to go it alone in their quest for new storage.

"Deregulation has had a positive impact on the development of storage in Ontario," states Jim Redford, Director of Business Development, Union Gas. "Deregulation has encouraged investment in storage infrastructure by providing investors like Union Gas and Market Hub Partners Canada the opportunity to manage the costs and revenues associated with the provision of services in a competitive market."

According to a Market Operations report from the OEB, natural gas storage capacity in the province was less than 250 billion cubic feet (Bcf) in January 2007. By January 2010, that number had increased to over 260 Bcf. And the OEB's projections see that number rising to close to 275 Bcf by January 2013.

Union Gas is by far the largest player in the market. The company currently has approximately 166 Bcf of working gas storage capacity in the province.

"Union Gas is ideally situated close to markets and has direct access to premium quality storage assets," comments Redford, who adds that the company's Dawn Hub is central to the North American supply and transportation of natural gas. "The Union Gas Dawn facility features more than 166 Bcf of storage in 23 depleted reservoirs, the largest underground natural gas storage facility in Canada, with all reservoirs interconnected to Dawn and acting as one integrated system."

The Consumer Choice

According to Natural Resources Canada, more than half of all Canadian homes are heated by natural gas. And by all accounts, that number continues to rise. Statistics from the Canadian Gas Association (CGA) suggest that there were approximately 5.7 million natural-gas "customers" in 2005. By 2009, that number had increased to almost 6.2 million.

Natural gas storage is used as a way to better meet the demands of these customers. Storage facilities are filled in the summer when demand is low and then drawn upon during the peak-demand winter months. The Ministry of Natural Resources states that demand on a very cold, winter day can be as much as five to six times more than on a warm summer day.

There are three main types of underground natural gas storage that are currently used today. These include: aquifers, salt caverns and depleted gas reservoirs. The latter represents by far the most common form of storage because they are generally the least expensive and easiest of the three options to develop, operate and maintain. The first successful underground storage of natural gas occurred in a depleted gas reservoir in Ontario in Welland County in 1915.

"Most of the natural gas storage in Ontario is in old gas wells and old depleted facilities in the Chatham/Tecumseh area," says Bryan Gormley Director of Policy, Economics and Information, CGA, who adds that there has been a record amount of storage in Ontario going into the winter season over the last couple of years. "This is a testament to the value of storage in the market."

Gormley suggests that approximately 15 per cent of the total annual North American natural gas demand is in storage by the month of October.

"The biggest load for natural gas in North America is, by far, heating," adds Gormley. "Winter is the biggest peak in demand. A second peak is starting to appear in the summer months, due to a changing pattern with power generators."

The development of new natural gas storage facilities is a critical component of the natural gas distribution infrastructure.

"Deregulation has drawn investment, especially from those entrepreneurial types that are ready to risk some money," states Gormley. "New facilities are being developed. It turns out that storage is one of the more valuable assets in the integrated natural gas system."

Boosting Capacity

The post-2006 focus on storage led to the development of significant natural gas storage capacity from a number of industry players. The OEB has identified the following improvements and/or new storage areas since deregulation:

- Market Hub Partners, new storage area in Lambton County (St. Clair Gas Storage Pool) with approximately 1.1 Bcf, completed in June 2007;
- Tribute Resources Inc. and Tipperary Gas Corp., new storage area in Huron County (Tipperary Gas Storage Pool) with approximately 1.8 Bcf, completed in April 2008 (Union Gas subsequently purchased 75 per cent of storage facility);
- Enbridge Gas Distribution, enhancement in Lambton County (Kimball Colinville Pool, Wilkesport Pool, and Coveny Pool) with no incremental capacity, completed August 2008;
- Union Gas, enhancement in Lambton County (Dow A Pool, Oil Springs East Pool, Payne Pool and Enniskillen 28 Pool) with approximately 2.0 Bcf, completed November 2008;
- Enbridge Gas Distribution, enhancement in Lambton County (Wilkesport Pool) with no incremental capacity, completed March 2009;
- Market Hub Partners and AltaGas, new storage area in Lambton County (Sarnia Airport Gas Storage Pool) with approximately 5.26 Bcf, completed April 2009;
- Union Gas, enhancement in Huron County (Tipperary Storage Pool), with no incremental capacity, completed September 2009;
- Union Gas, enhancement in Lambton County (Bentpath East Pool, Oil City Pool and Bluewater Pool) with approximately 0.52 Bcf, completed November 2009; and
- Enbridge Gas Distribution, enhancement in Lambton County (Corruna Pool, Seckerton Pool and Dow Moore Pool) with approximately 4.5 Bcf, scheduled for late 2011 completion.

Other projects currently in the works include:

- Tribute Resources and Bayfield Resources, new storage area in Huron County (Bayfield Pool and Stanley Pool) with approximately six Bcf; and
- Union Gas, new storage area in Lambton County (Jacob Pool) with approximately 2.45 Bcf, scheduled for completion sometime after 2012.

These latter two new storage pools provide evidence of the continued interest in growing the storage capacity in Ontario. They also represent two of the more interesting additions to the market in that they involve smaller, entrepreneurial players.

Heralding in Huron County

Tribute Resources Ltd. was founded in 1997 with the intention of exploring for new natural gas storage. The publicly traded company initially looked for new storage in existing geological reef pinnacles (where most of the natural gas pools are usually found and then converted into storage upon depletion of the reserves). For the most part, most of the storage pools in southwestern Ontario had been found in the reef pinnacles in Lambton County. This was due primarily to the location being readily accessible to the existing pipeline system that connects pools in this area to Union Gas' Dawn Hub.

"We got the idea of developing storage in Huron County," explains Jane Lowrie, president, Tribute Resources Ltd. "There wasn't a lot of exploration in the area because there weren't any pipelines connecting it to the main pipeline at the time."

Tribute Resources undertook the construction and commissioning of its first natural gas storage pool. The Tipperary Pool, as it is known, has up to three Bcf of storage capacity. Tribute Resources attained approval from the OEB and subsequently sold 75 per cent interest in the pool in 2007 to Union Gas. The pool became operational in 2008. It represents one of the first non-utility, competitive storage facilities to be connected to the Union Gas system and one of the first to be located in Huron County. Tribute Resources also owns a number of other pools and prospects located in Lambton, Huron and Kent Counties.

Of these pools, there are two in particular in which the company is currently seeking approval from the OEB. Together, the Bayfield Pool and Stanley Pool represent an estimated six Bcf of storage capacity in Huron County. As to whether the company will approach Union Gas once the storage areas are on-line, Lowrie remains mum about it.

"These two pools were part of our initial purchase of properties," she states, adding that today's current natural gas prices have slowed down exploration but she remains optimistic about the future. "We believe that storage prices will rebound soon."

Discovering New Formations

Up until recently, most of the gas storage within Ontario consisted of depleted gas pools found within reef pinnacles located in the Silurian "Guelph" geological formation. Most of these reefs, according to Simon Brame, President and Chief Executive Officer of Liberty Oil & Gas Ltd., were discovered in the 1950s and 1960s and have since been developed into storage facilities. But Liberty Oil & Gas and Union Gas could potentially change this scenario.

Liberty Oil & Gas was founded in 2005 via the acquisition of the assets of Veteran Resources, which also included a 50 per cent working interest in the Dover East Pool located in Kent County. The Dover East Pool consists of two producing formations: a natural gas-producing pool located in the Trenton Formation (about 850 metres below the surface) and, about 100 metres below that, an oil-producing pool located in the Black River zone. Unlike the majority of existing storage pools in southwestern Ontario, the Dover East Pool is situated in Ordovician aged rocks. The reservoirs in the Trenton and Black River Formations are in fractured and hydrothermal dolomites, which is quite different from the usual pinnacle reefs.

"The Dover East pool was discovered in 1983 and we thought that it would have storage capability because it has produced a significant amount of gas since then," explains Morley Salmon, director and vice president, Liberty Oil & Gas. "We're not in the storage business so we worked with Union Gas and said that we thought the Trenton pool would be good for storage. It was risky because no one had ever done something like this before. It was a completely new geological storage model for Ontario because it wasn't located in the reef pinnacles. The lack of recent discoveries in the pinnacles and the proximity to the Panhandle gas line were also important factors in looking at this as a new storage opportunity. "

Union Gas undertook a series of technical and engineering studies and eventually agreed that the Trenton Formation in one area of Dover East Field would be a candidate for natural gas storage. The final deal was signed in the summer of 2010 and this area of the Trenton Formation officially became the property of Union Gas. Union Gas subsequently developed the Jacob Pool in the Trenton Formation. The OEB approved the facility in July 2011 and Union Gas is now evaluating the capital and budget plans for proceeding with this project.



"The Jacob Pool is a depleted natural gas reservoir with approximately 2.63 Bcf of storage capacity," explains Union Gas' Redford. "It is located north of the Thames River and approximately 10 kilometres west of Chatham, Ontario. When completed, it will be connected to the Dawn Hub through new and existing Union Gas pipeline assets. It could be the first storage pool in Ontario to be developed within the Trenton formation."

In the meantime, Liberty Oil & Gas has given Union Gas the option to develop other natural gas pools in the area for additional storage.

"This option is pending the outcome of the Jacob Pool conversion," adds Salmon.

The company, however, has retained ownership of the oil-producing Black River pool, which could also become part of the storage project in the future.

"I think that the pinnacle reefs will continue to be the primary storage facility in Ontario," states Brame. "There are still many more Silurian pinnacles to be found, although they will typically be smaller than previously discovered. Given the interest that Union Gas has demonstrated in the Trenton zone, I hope that the Trenton undergoes some increased interest as an area for gas storage. Our next push will be the Black River. We're in no rush to give up the oil production of Black River but, as far as storage capacity goes, it seems the next logical step. "

Here Today, Gone Tomorrow

Although deregulation heralded in some brisk growth in natural gas storage in the province, it came with some challenges. The sharp growth in natural storage growth can be indirectly attributed to one of the contributing factors in the currently low price of natural gas. This may be good news for consumers but not so good for those companies looking to invest in new facilities.

"Natural gas storage values across North America have weakened recently due, in part, to the softening demand for natural gas, the number of storage additions placed in-service across North America in the past three years and the year-over-year increase in new production from unconventional supply basins, such as the Marcellus shale," states Union Gas' Redford.

According to numbers from the CGA's North American Natural Gas Supply: Increasingly Unconventional report, unconventional gas sources (which include coal bed methane and shale gas) represent an increasingly larger portion of the industry's natural gas supply. CGA reports that the amount of natural gas from unconventional sources has risen from nine per cent of the supply in 2000 to 25 per cent of the supply in 2010.

At the same time, the discovery of Marcellus shale gas basin (located throughout Pennsylvania, West Virginia, southern New York State, eastern Ohio, western New Jersey and western Maryland) is anticipated to play a significant role in the North American natural gas industry.

"If Marcellus production increases as forecast, it will impact flows of natural gas to Ontario and the U.S. northeast from their traditional supply regions in western Canada and the U.S. Gulf Coast. Already, the Marcellus shale has initiated several pipeline proposals that would connect Marcellus gas to the southern region of Ontario, where it could be connected to the existing pipeline system and stored in Ontario's largest underground facilities or sent directly to market," states the report, which goes on to suggest that unconventional gas will account for one third of total North America natural gas supply by the year 2030.

A Positive Outlook

Although current natural gas prices are lower than many utilities and industry players would like, the fact remains that natural gas remains a hot commodity still very much in demand.

"The storage business is cyclical, with growth expected over the long term," states Union Gas' Redford. "Storage will continue to provide security of supply, economical, high-demand seasonal balancing and optimum pipeline utilization. When gas isn't burned (but still being produced), pipelines can still maintain a level of capacity to fill storage for high-demand periods."

The need for storage in the Ontario market will be ever-present. True, there will be times when it may not make economical sense to invest in and develop new storage capacity but, if history is any indication, these times will come and go. Eventually, natural gas prices will rise and companies – big and small – will come flocking to the storage market.

"I think storage will remain a valuable asset," concludes CGA's Gormley. "The big distribution and utilities companies will always be looking to own some storage because it is so useful for them to have. And I think that over the next few years, we will probably see some more private entities getting into the game." ■

TAKING A LOOK AT FRACKING

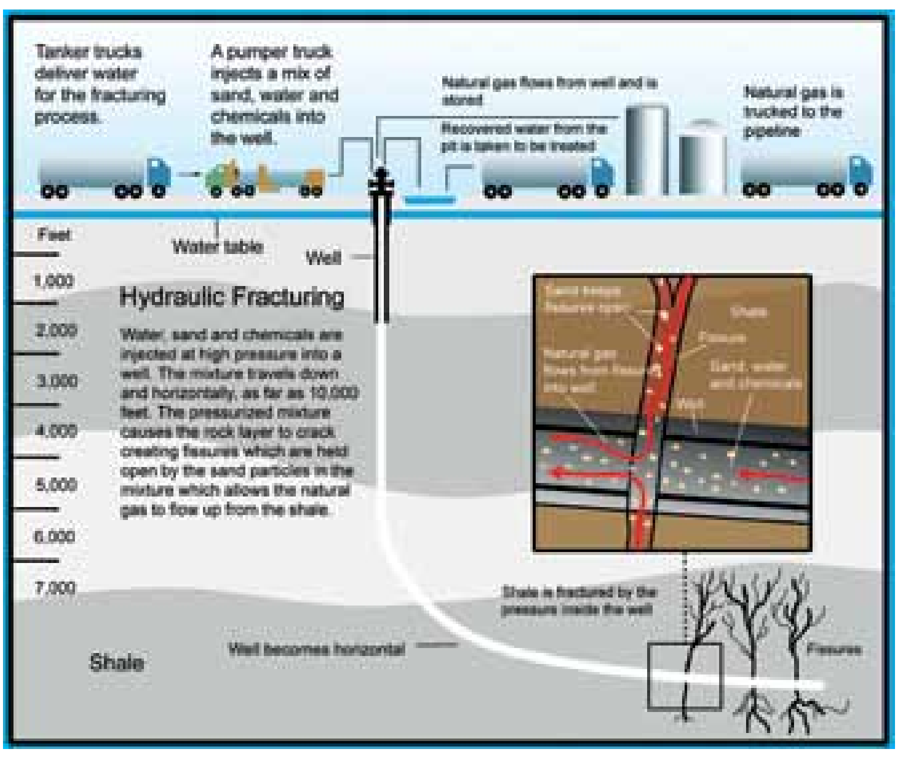
Love it or hate it, fracking has been used for over 60 years and remains an important component of oil and gas production

BY CHRIS BUNKA

Natural gas was first put to work in America, 1816, in Baltimore street lights, but never in the past two centuries has the debate over its production been more vociferous than today. So what's the issue?

Natural gas is a fossil fuel that emits less harmful emissions when burned than any other fossil fuel. The proportion of North American gas production coming from shale sources is growing rapidly and has already reached 30 per cent of all production. Shale gas production is not practical – and certainly not economically viable – without the use of hydraulic fracturing (fracking) as a vital production aid. According to the American Exploration and Production Council, "90 per cent of all natural gas wells drilled in America (about 35,000 a year) requires fracture stimulation."

The American Petroleum Institute says, "Hydraulic fracturing is a proven technology, used safely, for more than 60 years in more than a million wells. Without it, we would lose 45 per cent of domestic natural gas production and 19 per cent of our oil production within five years." (Hydraulic Fracturing: Unlocking America's Natural Gas Resources, July 19, 2010.) In Canada fracking has been used since the 1990s.



David MacLean, vice-president of the Alberta Enterprise Group, told *Resource World* magazine, "Fracking is the future of the natural gas (NG) industry and it's critical for industry to work hard to maintain a social license to develop these resources. Unlike man-made pollutants, most oil and gas seeps are produced by natural geologic processes that take place over millions of years. Though natural, they can pollute our air and waterways."

Oil and NG are part of the natural world and because they are comprised, in part, of toxic chemicals, they can have naturally-derived effects on parts of the environment.

Natural gas is comprised chiefly of methane, which is the smallest and lightest hydrocarbon molecule (one atom of carbon and four of hydrogen.) In part, because of the small size of the molecule, NG moves freely. Shale rock structures are so incredibly tight and non-porous that NG cannot flow at any reasonable rate to allow for commercial production. Hydraulic fracturing is used to crack open the shale in tiny fissures and allow the natural gas to be produced.

Fracking uses a water/sand/chemical slurry that is pumped underground at pressures of up to 15,000 psi, though usually less. Over 99 per cent of the fracking slurry is water and sand, but the chemical composition of the remaining one per cent causes concern. Chemicals such as ethylene glycol (antifreeze), isoproponal, 2-butoxyethanol, formaldehyde and others can be used. Diesel fuel is often used down hole in many oil and gas well drilling operations – not just in fracking – which is, of course, toxic in itself.

Oil and gas reserves are overwhelmingly most often found by identifying the subterranean geological formations called anticlines that "trap" hydrocarbons with their sealing characteristics. An underground oil or gas reservoir exists by virtue of the presence of that geological seal – preventing the "leakage" of the hydrocarbons in that location from traveling through the earth to some other location.

The issue of groundwater contamination is driven less from the presence of harmful chemicals deep underground (that occurs everywhere there are natural oil and gas reserves and regardless of whether we exploit them) but one of the movement of those substances to locations where they are not currently present.

Typically two to four million gallons of water is used to fracture a single well, and with multi-stage fracking and hundreds of wells in a region, even 1/10th of a percent of a harmful chemical can be significant. Some 50 to 80 per cent of the fluids used are recovered and usually re-used, while a significant portion remains in the earth. Oil and gas drilling and completion operations are large users of water, but as a whole, they are only incremental to overall consumption. "Calculations indicate that water use for shale gas development will range from less than 0.1 per cent to 0.8 per cent of total water use by basin." (USDOE Modern Shale Gas Development)

Companies are approaching the challenges in a variety of ways. EnCana Corp. and Apache Corp. have jointly spent over $10 million on a pilot project in northeastern British Columbia to utilize previously unusable salt water already naturally contaminated with hydrogen sulphide. Such low-quality water would normally never be used, but by treating it and removing the worst of the contaminants, the partnered companies are hoping to defuse some of the criticism they face regarding the use of fresh water for industrial purposes – water that their adversaries such as ranchers and environmentalists are adamant should be used for more benign, but vital purposes.

There is no form of energy production used today that does not use water somewhere in the process. This includes nuclear energy which uses vast quantities of water for cooling that is released back into the environment. Even solar energy production uses water in the manufacturing process for solar cells, for heat transfer in solar thermal systems and as cooling for concentrated solar systems.

Fracking is designed to open tiny cracks in the rock. The most commonly used size of frac sand, the sand that is designed to keep the cracks propped open. is between 0.42 milimetres and 0.84 milimetres. Typically a 10-foot or 20-foot crack would be sufficient. There is no commercial gain by extending the cracks beyond the limits of the NG reservoir.

It is not impossible that geological seals in the immediate vicinity of the well bore could, in theory, be compromised as a result of high pressure fracking. However, it is highly unlikely that hydraulically induced fracturing, designed to open tight rock for a distance of five to 20-feet, would normally be capable of destroying a geological seal that is often hundreds, even thousands of feet thick.

Still, the industry needs to acknowledge that simply by random chance, there is the possibility previously undetected, weak fissures in underground formations could serve as a conduit of weakness from an existing hydrocarbon trap. Millions of oil and gas wells have been drilled around the world. The production from every well involves the movement of hydrocarbons from a relatively stable underground source through a well bore and into a production facility.

An oil or gas well is much more than a hole in the ground; it is typically a multi-layered steel and concrete assembly. Surface casing is steel pipe that is surrounded by cement to isolate deeper oil and gas zones from the shallower zones or even ground level; any fluids or gases within that pipe are thereby prevented from "leaking" into the shallow ground that typically contains water aquifers.

The depth to which surface casing must be installed is strictly regulated. In Alberta, the Energy Resources Conservation Board approved a Directive on Surface Casing Depth Requirements as recently as December 14, 2010. Required depths of surface casing are complex, but, in almost all cases, must be a minimum of 25 metres below the deepest water well located within 200 metres of the proposed well. In many cases, the surface casing must also extend a minimum of 10 per cent of the true vertical depth of the hydrocarbon well.

A detailed series of papers were published by the American Petroleum Institute in the 1980s, detailing the suitability of well casings and the likelihood of well casing failure due to corrosion. The API study found that in a "modern horizontal well completion in which 100 per cent of the USDWs [Underground Source of Drinking Water] are protected by properly installed surface casings, the probability that fluids injected at depth could impact a USDW would be between 2 x 10^5 (one well in 200,000) and 2 x 10^8 (one well in 200,000,000)." (DOE: Modern Shale Gas Development)

Daniel Whitten, vice-president of Strategic Communications for America's Natural Gas Alliance (ANGA) asserts that, "Hydraulic fracturing is critical to our nation's clean energy future." Because of its vital importance, he believes it is in industry's own best interests to conduct all aspects of exploration and production under the highest standards possible. "Before hydraulic fracturing chemicals go "downhole," integrity tests are conducted to ensure wells are properly cemented and secure."

Improper or deficient well construction presents risks to the environment from fracking as well as production. The infamous 2010 Macondo oil spill in the Gulf of Mexico has been blamed, in part, on inadequate well construction. David MacLean of the Alberta Enterprise Group told Resource World that, "The Gulf Coast spill reminded us that there is no risk-free method of resource extraction, but fracking has been around for a long time, so this technology has proven itself."

Regulation of shale gas production and hydraulic fracturing is extensive. Most oil and gas (O&G) regulation is at the provincial or state level. In Canada, this includes the National Energy Board, the Alberta Utilities Commission and the Energy Resources Conservation Board. While over 30 U.S. states produce some NG, just five – Texas, Wyoming, Oklahoma, Louisiana and New Mexico – together produced 65 per cent of all the gas produced in the U.S. in 2009. Alberta alone produces five trillion cubic feet per year. Regulations in these jurisdictions are paramount.

In the U.S., the Department of Energy (DOE) formed the Energy Advisory Board Subcommittee on Shale Gas Production to produce "a report on the immediate steps that can be taken to improve the safety and environmental performance of shale gas development."

This subcommittee is chaired by MIT professor, John Deutch, who said, "Industry, working with state and federal regulators and public interest groups, should increase their best field engineering practices and environmental control activities by adopting the objective of continuous improvement, validated by measurement and disclosure of key operating metrics. This is the surest path forward to assure that shale gas is produced in an environmentally sound fashion, and in a way that meets the needs of public trust."

"The development of shale gas is one of the biggest energy innovations, if not the biggest, in several decades," continued Deutch. "It has reduced energy costs and created hundreds of thousands of jobs. But to ensure the full benefits to the American people, environmental issues need to be addressed now – especially in terms of waste water, air quality, and community impact."

Recently, the Secretary of Energy Advisory Board Subcommittee (SEAB) on Shale Gas Production released its final report on the environmental and safety aspects of shale gas development. Their judgment was, "that if action is not taken to reduce the environmental impact accompanying the very considerable expansion of shale gas production expected across the country, there is a real risk of serious environmental consequences and a loss of public confidence that could delay or stop this activity."

On December 8, 2011, the EPA released a preliminary report that said it may have found a link between chemicals used in well fracking in a field in Pavillion, Wyoming, and a nearby water aquifer. According to the report, "the EPA constructed two deep monitoring wells to sample water in the aquifer." The draft report indicates that ground water in the aquifer contains compounds likely associated with gas production practices, including hydraulic fracturing. EPA also re-tested private and public drinking water wells in the community. The samples were consistent with chemicals identified in earlier EPA results released in 2010 and are generally below established health and safety standards.

The testing methodology was quickly criticized by industry, pointing out the depth of the two test wells far exceeded that of any actual water wells in the area and provided an indication only of the migration of substances below the traps that separate most drinking water sources from deeper geologic horizons. It does seem to indicate, however, a potential link of migration from a hydrocarbon reserve to a water reserve.

Canada's Federal Environment Minister, Peter Kent, requested a study on the development of Canada's shale gas resources from the nonprofit Council of Canadian Academies. This is expected to be an independent, expert-panel assessment of the state of scientific knowledge on potential environmental impacts.

Maude Barlow's Council of Canadians Acting for Social Justice has criticized the study (not expected before early 2013) as too slow in arriving, and is calling for a moratorium on all hydraulic fracking in Canada. The province of Québec has already imposed a temporary two-year moratorium, expiring in March, 2013, as it examines the issues surrounding its use.

Hydraulic fracturing has already been the subject of a number of exhaustive studies.

The U.S. EPA is conducting a detailed study of the impact on drinking water from fracking activities. The Energy Policy Act of 2005 is criticized by those displeased with the decision to exempt hydraulic fracturing under the Safe Drinking Water Act (SDWA) because of former Halliburton executive Dick Cheney's perceived influence. The U.S. Congress instead maintained the state regulatory system long in place. Congress did reserve the right of applying the SDWA already in place to hydraulic fracturing if and/or when diesel fuel was utilized down hole.

In May 2009, the Ground Water Protection Council released a review of oil and gas regulations as they existed in 27 states in the U.S., and among many findings, reported that most have existing requirements to protect groundwater through the encasement of wells with cement.

Michael Nickolaus was the author of the report, and as reported by ProPublica.org, says, "well construction, especially the cementing process that keeps drilling fluids and gas from seeping into groundwater, is more important than the fracturing issue."

The report points out that casing regulations are inconsistent and, in many cases, may not be thorough enough to reliably protect against contamination.

All jurisdictions need to require that O&G companies, in advance of undertaking a fracking project, provide a list of all chemicals and substances to be used downhole. The ANGA and its member companies support publicly available disclosure of hydraulic fracturing fluids through a stat-based registry launched by the IOGCC and the GWPC. Companies need to be held responsible for any contamination of drinking water aquifers that does occur as a result of their activities. Deeper well casings might reduce the likelihood of unintended migration and would be easy to regulate.

The O&G industry would do itself a favour and make the world a better place if it stopped using any toxic chemicals downhole in the fracking process, and found non-toxic replacement compounds. Most reasonable people will not vilify an industry if it is not just following existing regulations, but in particular, when it is continually improving itself. Daniel Whitten, vice-president of ANGA says, "continued advancements mean fewer wells recovering even greater reserves and creating less surface disturbance and waste in the communities where we work."

Consider the automotive industry: 33,963 people died in automobile accidents in the U.S. in 2010. There is no public call for a banning of all automobile use because society understands that the collective use of the automobile outweighs the damages, however tragic those damages might be. Instead, all parties work together to make automobiles safer. In fact, the death rate in 2010 of 1.16 deaths per 100 million miles travelled, is the lowest traffic caused death rate ever recorded in the U.S.

Oil and NG travel naturally through underground rock formations; that technology is not capable of preventing. Hydraulic fracking unlocks vast quantities of NG for our use. The benefits of NG use outweigh the potential damages from the possibilities of rarely occurring underground migration of NG.

Humanity has an obligation to hold itself to a higher standard than it holds the natural world. After all, we benefit greatly from manipulating that world to suit our needs. As we develop natural resources to improve the lives of all, we must use the best practices that science and economics will permit, and continually upgrade those practices. This will form the foundation of a vibrant North American natural gas industry for generations to come.

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INVESTMENT OPPORTUNITIES AND NEWS

PLUGGED IN

Requirements for well abandonment

BY MUNTAZIR PARDHAN, P.ENG., ASSOCIATE, DILLON CONSULTING LIMITED
K.J. O'SHEA, P.GEOL., PARTNER, DILLON CONSULTING LIMITED

Oil and gas industry practices in Ontario are governed by the Oil, Gas and Salt Resources Act (OGSRA), as administered by the Ontario Ministry of Resources (MNR). The requirements for oil and gas well abandonment are specified in the Ontario Standards referenced in O.Reg. 245, under the OGSRA.

In July 2011, Ontario Regulation (O.Reg.) 511/09 amending O.Reg 153/04 – Records of Site Condition (RSC), under the Environmental Protection Act, came into full effect. The amendments included updated soil, groundwater and sediment standards, detailed requirements for conducting and reporting Phase I and II Environmental Site Assessments (ESAs), a streamlined risk assessment tool, and updated requirements to support the filing of an RSC. The Ontario Ministry of the Environment (MOE) administers O.Reg. 153/04.

The amendments to O.Reg. 153/04 brings the environmental component of site reclamation and restoration under the purview of the MOE. The downhole component of the well abandonment, and the removal of equipment, is covered off in the Ontario Standards and administered by the MNR.

The vast majority of oil and gas wells in Ontario are located in rural agricultural areas. In many cases, once a well has been drilled and tied into a production facility, the "footprint" of the activity is less than 10 m2. O.Reg. 153/04, by definition, regardless of the small footprint of the ongoing activity, considers the individual well site to be an industrial site. When a well has reached the end of its effective production capacity and is abandoned, the land comprising the well site is typically returned to the landowner. The abandonment of the well is undertaken by the well owner in accordance with the requirements in the Ontario Standards. Since the well site was used for an industrial purpose, as defined by O.Reg. 153/04, and it is intended that land use at the well site may be returned to a more sensitive land use (e.g., agricultural), reclamation of the well site must follow the O.Reg. 153/04 process and an RSC must be filed with the MOE before the land use changes.

The minimum requirement to file an RSC is the completion of a Phase I ESA. The objective of the Phase I ESA is to determine the likelihood that contaminants have affected land or water on, in or under the subject property, or in this case the well site and to identify potentially contaminating activities and corresponding contaminants of concern. In the past, a Phase I ESA was completed following the Canadian Standards Association (CSA) Phase I ESA Standard (Z768-01). The new requirements for a Phase I ESA prescribed in O.Reg. 153/04 are more prescriptive and go beyond the CSA Standard. Under O.Reg. 153/04, the Phase I ESA must be conducted or supervised by a Qualified Person (as defined by the regulation). A Qualified Person for Environmental Site Assessments is someone who holds a current licence as a Professional Engineer or a Professional Geoscientist in the Province of Ontario. The assessment itself includes a considerable amount of background research on the well site and the surrounding lands, and requires that a legal survey of the well footprint to be completed for the Phase I ESA.

If the Phase I ESA determines that it is likely "one or more contaminants have affected any land or water on, in or under the Phase One property," the need for a Phase II ESA is trigged as an additional prerequisite to filing an RSC. In part, this determination is based on the identification of potentially contaminating activities (PCAs) on the Phase One property. O.Reg. 153/04 contains a list of PCAs that includes "discharge of brine related to oil and gas production" and "hydrocarbon production." As a result, if an individual well has produced oil/natural gas or has discharged brine, it triggers the requirement for a Phase II ESA to be completed in support of an RSC. A Phase II ESA must also be conducted or supervised by a qualified person, and typically includes intrusive soil and groundwater collection and testing. As with a Phase I ESA, O.Reg. 153/04 is prescriptive in the approach that must be followed to conduct the assessment and report the results.

For an RSC to be filed based on a Phase II ESA, soil, groundwater and sediment samples that are collected and analysed as part of the Phase II ESA must meet the appropriate standards in the Soil, Ground Water and Sediment Standards for Use Under Part XV.1 of the Environmental Protection Act (April 15, 2011). The appropriate standards are selected based on land use, ground water use (i.e. potable or non-potable), and soil texture (i.e. coarse or medium/fine-textured). The contaminants that are often associated with oil and gas wells include hydrocarbons, salts and other inorganics. At a site that has soil, groundwater or sediment that does not meet the applicable standards, the following actions are often taken prior to filing an RSC:

- Remedial actions (e.g. soil excavation) can be undertaken to reduce the level of contamination to below the applicable standards
- A risk assessment can be completed to show that the levels of contamination present are not a significant risk to human health or the environment, generate property specific standards that are protective of human health and the environment and identify risk management measures to reduce potential risks to acceptable levels; or
- A combination of remedial actions, risk assessment, and risk management measures may be implemented to support the RSC.

Once the RSC is filed by a QP, the MOE can either acknowledge the RSC, return the RSC for revision (for a prescribed defect) or request that the supporting Phase I and/or Phase II ESA reports be submitted for review prior to making a decision. The prescriptive nature of the Phase I and Phase II ESA requirements suggests the MOE may reject any Phase I and Phase II, and hence the RSC, that does not absolutely adhere to those prescriptive elements. ■

ALL IS WELL

Regional groundwater systems in southern Ontario.

BY TERRY CARTER, CHIEF GEOLOGIST, PETROLEUM OPERATIONS, MINISTRY OF NATURAL RESOURCES, LONDON, ONTARIO

According to the Geological Survey of Canada, roughly a quarter of Ontario's residents, representing half a million households, are reliant on groundwater as a source of potable fresh water. Most of these households are rural and represent an even larger proportion of the land area of southern Ontario. But where does this water occur? How much is there? Is it all potable? This information is needed by Ontario municipalities to protect source water supplies.

In the context of this article, groundwater is loosely defined as any water, fresh or otherwise, occurring in the subsurface, as opposed to surface water. Groundwater occurs in pore spaces of rocks and sediments. Surface water occurs in lakes, rivers, streams, wetlands and oceans, in the atmosphere and frozen in polar ice caps. An aquifer is any underground layer of water-bearing rock or sediment from which water can be usefully extracted using a water well. An aquitard is a layer of rock or sediment that does not readily yield water and may act as a barrier to water movement.

To date, groundwater mapping in Ontario has been inadequate to provide even a basic understanding of where our groundwater resources are located, and the quality and quantity of these resources. This article is a brief summary of progress on an ongoing study by the Petroleum Operations Section of the Ministry of Natural Resources (MNR) to partially address this lack of information. This study is complementary to groundwater mapping being undertaken by the Ontario Geological Survey which is directed at shallow fresh water aquifers in the glacial drift overlying bedrock and in shallow bedrock. Long-term goals of the MNR study are to document:

- rocks which contain water (aquifers) and oil and gas (reservoirs)
- water type in the aquifers, i.e. fresh water v.s. saline and sulphurous water
- rocks that form aquitards
- regional flow directions of water
- subsurface drilling hazards posed by highly permeable rock formations (loss of circulation)
- areas underlain by aquifers capable of flowing at the surface (artesian flow)
- geochemical fingerprints of water in regional aquifers

All petroleum wells drilled in southern Ontario intersect at least one potable water zone, may intersect several aquifers containing saline and/or sulphurous water in deep bedrock and are anticipated to encounter hydrocarbons in the target formation. These aquifers, and the hydrocarbon-bearing formations, must be isolated from each other so that fluids cannot move from one to the other. This is of particular importance to prevent contamination of potable groundwater by the deeper fluids. Some aquifers are locally capable of flow at the surface and must be isolated during drilling. Other formations contain sulphur water (dissolved H2S) which is corrosive to steel casings and must be isolated by sulphur-resistant cement. Bedrock aquifers with high permeability caused by cavernous porosity or open fractures constitute drilling hazards that may result in loss of drilling fluid circulation and possibly loss of well control. The results from this study will result in better well designs and drilling and plugging programs by the petroleum industry and reduce the associated risks and hazards to workers, the public and the environment.

The improved understanding of subsurface conditions will be used by MNR, as regulator of the industry, to develop and design operating standards, inspections and investigations, and plugging programs for orphan wells. The information will also enhance and provide a scientific basis for the Ministry's regulatory review process of proposed drilling programs, injection permits for the purpose of secondary recovery and proposals for subsurface disposal of oil field fluids.

Groundwater Data Sources

Two databases are the principal sources of basic information on the occurrence of groundwater and subsurface geology in southern Ontario. The Water Well Information System, maintained by the Ontario Ministry of Environment, contains over 600,000 water well records, including basic data on well location, sediment or rock type, water quality and quantity, static water level, pump rates and well construction. These wells are relatively shallow, reaching total depth only a few metres or tens of metres into bedrock or within the glacial drift overlying the bedrock.

The principal source of information on water in deep bedrock is the Ontario Petroleum Data System, which consists of a relational da-

Steel casings recovered from orphan wells plugged by the Abandoned Works Program of the MNR, illustrating corrosion by exposure to sulphur water in subsubsurface aquifers.

tabase maintained by the Petroleum Operations Section of the Ontario Ministry of Natural Resources. These records provide geological, drilling and engineering information for over 26,000 petroleum wells drilled in Ontario since 1858. Stored data include geographic coordinates for well location, status, depths, geological formation tops, well construction, oil/gas/water intervals, geophysical logs, cored intervals and drill cutting rock samples. Water interval data includes depth, elevation, static level, water type and geological formation. Without this database the present study would not have been possible.

Basic well data can be viewed, queried, mapped and downloaded free of charge from the Oil, Gas and Salt Resources Library's website www.ogsrlibrary.com. Access to digital geological data, including water intervals, is restricted to corporate and individual members of the Oil, Gas and Salt Resources Library or can be purchased. Water well data from across southern Ontario is publicly available at www.gw-info.net. The water well data has been reformatted by the Oil, Gas and Salt Resources Library and is available to their members on their website.

Geology

Bedrock in southwestern Ontario is comprised of marine sedimentary rocks deposited in thick layers on the floor of a shallow sea that covered this part of eastern North America from approximately the late Cambrian to at least the early Mississippian and possibly into the Permian (approximately 501 to 250 million years ago). The youngest preserved strata in southern Ontario are Upper Devonian (360 million years old). Maximum preserved thickness of sedimentary rock is 1,400 metres. Approximately 1,300 to 2,000 metres of younger bedrock was eroded away during the past 250 million years.

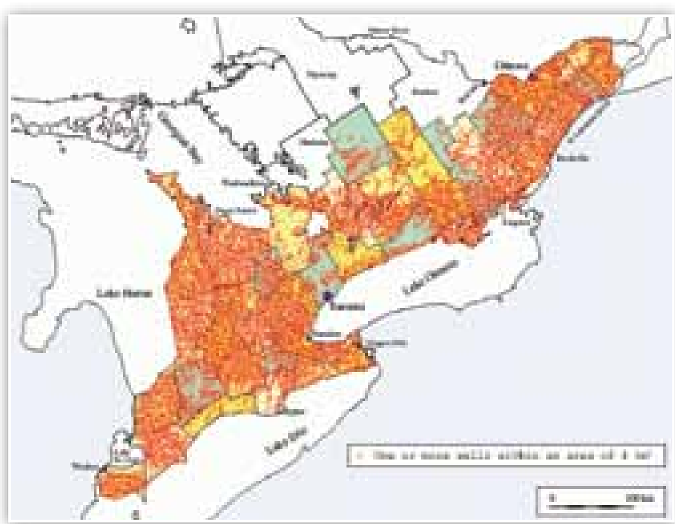
Generalized bedrock geology map of southern Ontario, showing linear outcrop belts of stratified Paleozoic sedimentary rocks ranging from Cambrian to Upper Devonian in age. Crystalline metamorphic and igneous rocks of the Canadian Shield are shown in pink. Regional dip of the Paleozoic strata is to the southwest.

Preserved rock types include limestone, dolostone, sandstone, shale, siltstone, and beds of salt. These rocks have varying porosity and permeability depending on how they were formed or altered over time. Of particular importance are the presence of several regional unconformities and disconformities which represent periods of post-depositional exposure and erosion in the geologic past. During these periods, where the exposed rocks were carbonates or evaporites they were subject to dissolution by acidic surface waters that greatly enhanced the rock's porosity and permeability. These rock features, known as "karst" intervals, appear to form most of the regional bedrock aquifers in southern Ontario.

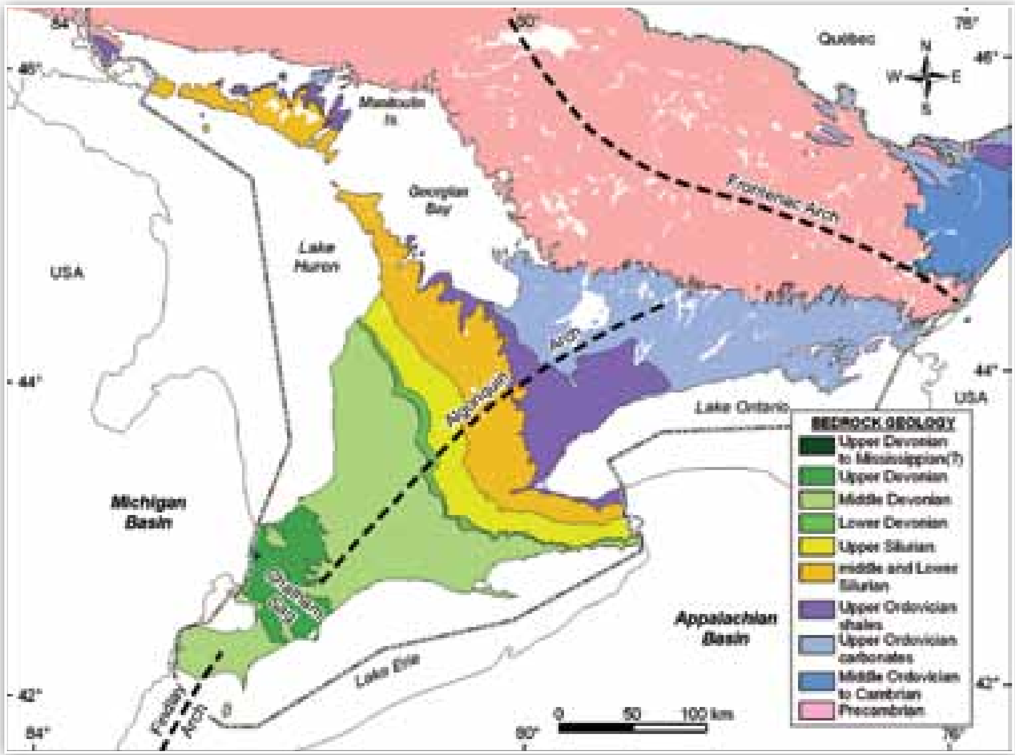
In most of southern Ontario the bedrock is overlain by a relatively thin veneer of unconsolidated sediments of glacial or recent origin. The thickness of these sediments ranges from zero to about 200 metres, but most commonly measures several tens of metres. These sediments are collectively referred to as overburden or drift and consist of clay, silt, sand, gravel and glacial till. They are overlain by variable amounts of topsoil and sometimes locally with peat beds in areas of poor drainage.

The glacial sediments were deposited during several episodes of continental glaciation which affected all of Ontario from 10,000

Locations of petroleum wells in southern Ontario.



Locations of water wells in southern Ontario.



Left: Generalized bedrock geology map of southern Ontario, showing linear outcrop belts of stratified Paleozoic sedimentary rocks ranging from Cambrian to Upper Devonian in age. Crystalline metamorphic and igneous rocks of the Canadian Shield are shown in pink. Regional dip of the Paleozoic strata is to the southwest.

Below: Stratigraphic chart of bedrock of southern Ontario showing named geological formations from youngest (at top) to oldest (at bottom), their geological ages and positions of major unconformities (vertical hatch pattern). Karstification of carbonate rocks and evaporites associated with some of these unconformities created extensive aquifers in the bedrock.

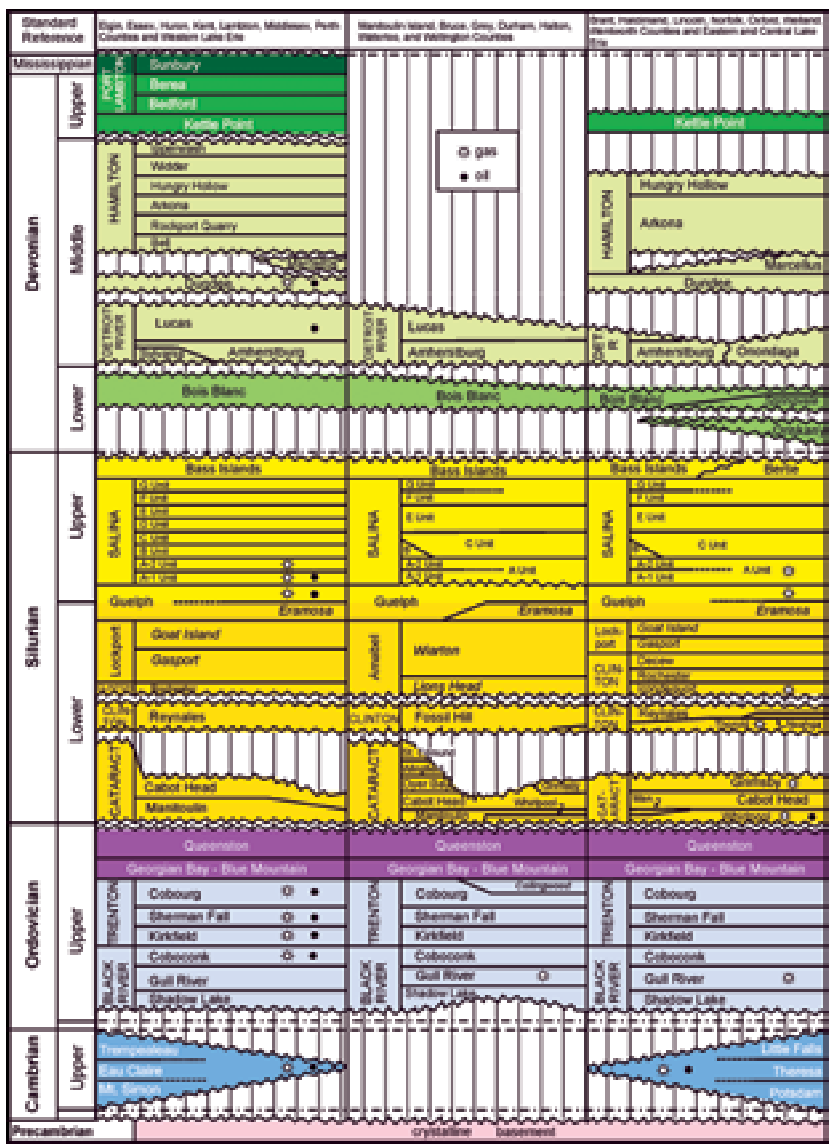
to 1.8 million years ago. These sediments can have pore space that exceeds 40 per cent to 50 per cent of its total volume, resulting in a large groundwater storage capacity. Glacial sediments are highly variable and can result in complex local aquifer systems having multiple layers and limited lateral extent. Glacial sediments usually exhibit much greater porosity and permeability than bedrock formations.

Aquifers

At a regional scale, aquifer systems in southern Ontario can be divided into a complex shallow fresh water system of local aquifers and aquitards within drift and the uppermost few metres of bedrock; and a deep bedrock system comprising thick regional aquitards of low-porosity and relatively impermeable bedrock containing a few confined thin aquifers of saline and sulphurous water of local to regional extent.

A scaled geological cross-section across southern Ontario showing regional southwesterly dip of bedrock formations and occurrence of water, oil and natural gas in these layered rocks. Fresh water (blue) is confined to a thin veneer of glacial drift and very shallow bedrock. Salty water containing dissolved H2S (sulfur water), shown in yellow, occurs at intermediate depths. The deepest rocks contain highly saline water with no dissolved H2S (orange). Water flows downwards from topographic highs and down regional dip of confining geological formations. There may be lateral movement of water along strike (circles with x symbols) due to buoyancy effects of deep saline brines.

The drift sediments are porous and permeable to varying degrees and act as a sponge soaking up and filtering rain-



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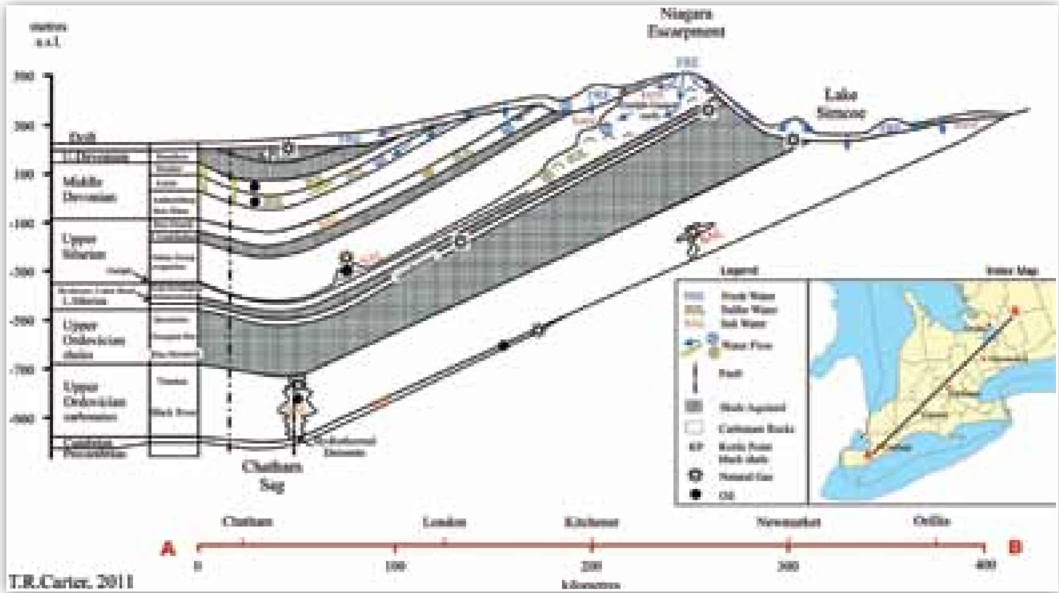


fall in topographically high (recharge) areas and discharging it back to surface water bodies in topographically low areas. Regional flow directions in the drift are inferred to be topography-driven from the highlands of the Niagara Escarpment towards the topographic lows of lakes Erie, Huron, St. Clair, Ontario and Simcoe. These drift aquifers constitute active flow systems and are the source of most of the potable fresh groundwater in southwestern Ontario. By comparison most of the bedrock strata have low porosity and permeability, do not produce water, and can be classed as aquitards.

Shale strata form regional aquitards within the bedrock layers, the thickest and most extensive being the Upper Ordovician Queenston, Georgian Bay and Blue Mountain formations which exceed 300 metres in combined thickness. Evaporites of the Silurian Salina Group form another regional aquitard with preserved thicknesses of halite locally exceeding a combined thickness of 230 metres. Most of the carbonate rocks are also aquitards, in particular the thick limestones of the Trenton and Black River groups. Confined between these aquitards are several aquifers of regional extent identified from petroleum well records. Most of these aquifers are saline, i.e. they contain non-potable formation water of moderate to very high salinity. Regional saline aquifers occur in the Lucas and Dundee formations, the Guelph Formation, the Bass Islands and the Cambrian. Saline aquifers of more limited extent have been documented in other formations. Sulphur water is frequently present at shallow to intermediate depths in these bedrock aquifers. This may represent a mixing zone between meteoric water and brines at deeper depths but there is currently insufficient data to support this hypothesis. Flow in these deep aquifers has not been demonstrated. They may be stagnant or at best exhibit very slow flow due to lack of pathways for discharge.

The only potable water within bedrock occurs where porous bedrock occurs at the surface or immediately beneath drift, in particular where the bedrock is karstic, i.e. carbonate rocks have been dissolved by acidic surface water or groundwater. To date, the deepest documented occurrence of fresh water beneath the top of bedrock is 200 metres, but usually is confined to the uppermost few metres or tens of metres of bedrock. At these shallow depths the saline formation waters have been replaced by fresh water of meteoric or glacial origin.

The most regionally extensive fresh water aquifer in southern Ontario occurs at the contact between the drift and bedrock. Except for the uppermost few metres, the bedrock is relatively impermeable and forms a barrier to downward percolation of fresh meteoric water through the overlying drift. Fresh water collects at this lower confining surface beneath a very large portion of southern Ontario. The uppermost few metres of bedrock are usually porous and permeable due to fracturing and weathering, regardless of bedrock type. These few metres of porous bedrock form part of this “contact” or “interface” aquifer. Flow directions in the contact aquifer are controlled by topography of the bedrock surface.

Work in Progress

The MNR is producing maps to document the geographic distribution of water, by type, in each of the regional bedrock aquifers. Maps showing static levels of water will also be constructed for some of these aquifers. Publication is anticipated sometime in the next year.

A three-year project to document unique geochemical fingerprints of the deep saline aquifers is underway, using the knowledge gained from the present work to identify and constrain locations and intervals for water sampling. The project is a joint investigation with the University of Western Ontario, under the direction of Dr. Fred Longstaffe. Geochemical parameters which will be determined include isotopes of sulfur, hydrogen, and oxygen, and concentrations of dissolved cations and anions including Ca, Na, Mg, K, Br, Cl, HCO3 and SO4. Natural gases are also being sampled to determine the unique isotopic compositions of carbon, oxygen and hydrogen diagnostic of different geological reservoir types and plays. The results will be used to design a practical geochemical tool to enable Abandoned Works Program staff to determine the geological source of waters and gases escaping to the surface up unplugged orphan petroleum wells. This knowledge will improve design of plugging programs and help reduce plugging costs. The results of the geochemical analyses will be made available to industry and the public for development of additional practical applications.

Practical Applications

Drilling and operation of petroleum wells in Ontario is regulated under the Oil, Gas and Salt Resources Act, regulation 245/97 and the Provincial Operating Standards. Section 3 of the Standards requires the operator of a well, “plan and effect a casing and cementing program for the well to protect all fresh water horizons and all potential oil-bearing or gas-bearing horizons penetrated during drilling operations and to prevent the migration of oil, gas or water from one horizon to another.”

The new understanding of groundwater occurrence in the deep subsurface provides the regional information needed by industry to comply with this requirement and by the MNR to monitor compliance. Protection of potable groundwater is achieved in the early stages of drilling a new well by installation of a steel “surface casing” that prevents contamination by any saline and sulphurous water or hydrocarbons encountered in deep bedrock formations. Installation of additional casings at deeper depths prevent migration of saline or sulphurous water or hydrocarbons up the well-bore to the surface.

The study has identified and mapped localities with deeper occurrences of fresh water than previously appreciated and is already in use by the MNR to review new drilling proposals. These deep aquifers also constitute a previously unmapped potential supply of potable water.

Deep saline aquifers do not produce potable water but may have other uses. Salty formation water is a nuisance by-product of production of crude oil and natural gas from petroleum wells in southern Ontario. This “oil-field fluid” is injected into subsurface saline aquifers, often the same formations from which it was produced, using oil-field fluid disposal wells. The deep saline aquifers mapped in this project and shown above are candidate horizons for disposal of oil field fluids. A total of 39 oil field fluid disposal wells are currently licensed for this use in Ontario under the Oil, Gas and Salt Resources Act.

Some subsurface brines have unique chemical compositions, such as high calcium content, which make them valuable for commercial purposes. This formation water is produced from special brine production wells in a very few locations. Where the water contains dissolved H2S, steel casings must be protected from corrosion by a sheath of sulphur-resistant cement. Detailed mapping of these areas is in progress.

Saline aquifers in neighbouring parts of the United States are proposed to be used for injection and permanent storage of carbon dioxide, captured from large industrial point sources, as a climate change strategy. There have been preliminary investigations of its feasibility in Ontario.

The results of this study and ongoing work by the Ontario Geological Survey is improving our knowledge of the occurrence of groundwater in Ontario. This information is critical for protection of potable water supplies, design of drilling programs by the petroleum industry and effective regulation by the MNR. ■

NO STONE UNTURNED

Applied research in Ontario's petroleum geology.

BY BURNS A. CHEADLE, ASSOCIATE PROFESSOR AND
BILL BELL CHAIR IN PETROLEUM GEOLOGY,
DEPARTMENT OF EARTH SCIENCES, THE UNIVERSITY OF WESTERN ONTARIO

The village of Oil Springs is a quiet place, typical of many of the small hamlets scattered amidst the gently rolling farmlands of southwestern Ontario. It is a destination requiring a deliberate sense of purpose, offset and partially obscured from infrequent travellers on Lambton County Road 21. Attentive drivers may take note of the alternative name for this stretch of rural highway, Oil Heritage Road, and momentarily ponder the significance.

The bucolic hush of contemporary Oil Springs belies a clamorous legacy that fundamentally shaped the modern world, setting into motion economic and political forces propelling the fate of nations, and humanity writ large. For it is on this site, in 1858, that James Miller Williams seized upon an unexpected discovery of free oil while digging a water well and, with entrepreneurial acumen, set about the construction and operation of a pot still for the purpose of manufacturing, transportation and sale of a refined petroleum product. In doing so, Williams founded the first integrated oil company in North America. His success did not go unnoticed.

Within the year, word of the Williams operation attracted a wave of fortune-seekers to the Oil Springs area ,as well as the Oil Creek Valley of Pennsylvania, where Edwin Laurentine Drake demonstrated the practicality of drilling using pipe to prevent collapse of the well.

The singular accomplishment of both Williams and Drake was not the discovery of new oil pools, but demonstration of the ability to produce petroleum in large volumes. This allowed them to capitalise on Abraham Gesner's research and development of the process to refine crude oil into kerosene, a value-added illumination product that would displace whale oil in lamps, and ultimately create entirely new markets.

Many competing claims have been made with respect to founding of the modern petroleum industry, and contentions of prior art continue to be debated to this day. Indeed, national pride hangs in the balance for the champions of opposing arguments. The objectivity of history, disputatious in its own right, inclines to the point of view that both Williams and Drake benefited greatly from the precedent research of their time. In both cases, the oil was not "discovered," having been procured at sites of surface seeps described by prior surveys. The Williams No. 1 well was situated in the Enniskillen Township "gum beds" described by chemist and geologist Thomas Sterry Hunt, who reported on his analysis of the potential commercial value of the bitumen in the Geological Survey of Canada's 1849 Report of Progress.

Drake's "discovery" on the bank of Oil Creek, Pennsylvania was in-

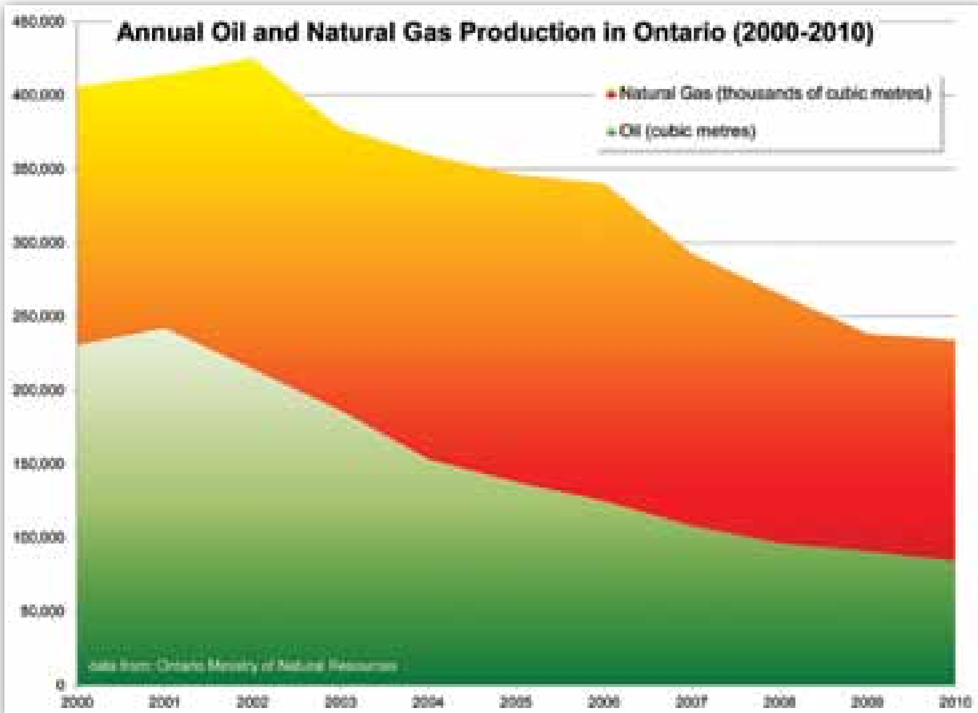


Figure 1: Ontario's oil and natural gas production has declined considerably through the past decade.

spired by an encouraging research report written in 1855 by Yale chemist Benjamin Silliman, Jr. Silliman had been supplied with a sample of "rock oil" swabbed from Oil Creek (so named in 1755) where both European settlers and the indigenous Seneca people had been skimming oil from the creek water for various uses since first settlement of the area.

A pattern was set at the dawn of the modern petroleum industry that has continued to this day – applied scientific research is a vital catalyst to propel exploration and development of this essential commodity. Chemical and engineering studies have been instrumental in developing production and processing technologies, but geological research has played the critical role of identifying new resources. Ontario's oil and gas industry has benefited from the products of such research throughout its storied past, and will rely on new innovations for its future vitality.

There is a well-established tendency for early exploration efforts to discover the largest and most easily-detected prospects, with subsequent campaigns increasingly resorting to the search for smaller and more subtle targets. Ontario has not enjoyed an exception to this general pattern. Whereas early oil exploration in southwestern Ontario yielded large oil and gas pools from shallow structural domes in the Devonian play, later drilling proved disappointing and new plays required significantly more perseverance for detection and production.

In Ontario's case, that persistence paid off with the discovery of significant natural gas reserves in the Silurian sandstones and carbonate reefs beginning in the late 1800s and continuing through to the 1960s. Oil discoveries, however, proved to be more elusive. It was not until the 1980s when the combination of evolving seismic technology and sophisticated applied research into porosity creation by circulating basinal fluids gave rise to a string of oil discoveries in the Ordovician Trenton-Black River play.

Although many details of this mechanism are hotly contested and remain fertile ground for future research, the oil discoveries in Ontario's Trenton-Black River hydrothermal dolomite play are proof of the catalytic power of applied geoscience research in reinvigorating a dormant industry. The afterglow of successful integration of research insights, however, is tempered by the inevitable decline of new discoveries.

Today's Ontario oil and gas industry faces an all too familiar challenge of reviving flagging production. The past decade has witnessed a 65 per cent drop in oil production and 45 per cent drop in natural gas production (Figure 1). The oil decline is particularly vexing as it has occurred during the same period that oil prices have tripled. Not only is the loss of royalty revenues a hard blow to strained provincial coffers, but vital investment and spin-off benefits are being drawn away at a time when every job saved is a exacting victory in Ontario. One hundred and fifty years of intense exploration of a relatively small oil patch has left few stones unturned, begging the question if applied research can reprise past victories by lighting the way to new prospects. The answer, it seems, is to look at those stones that were previously dismissed as unworthy of attention.

For most of their history, petroleum explorers single-mindedly sought after only those reservoir rocks that exhibited the large, interconnected pores that afforded easy flow of oil and gas from their sponge-like texture. Wells drilled into such rocks yielded their treasure with little more effort than installation of a pump, some obligingly flowing oil and gas to the surface ready for the taking. As the supply of these prolific reservoirs dwindled, the need to replace declining production forced operators to turn to ever more reluctant reservoirs that required increasingly sophisticated encouragement to stimulate production. Throughout this dismal exercise, though, the hunt continued to focus on target formations that bore at least a superficial resemblance to the sandstones and limestones that once delivered prodigious flows. Even these pale pretenders are now becoming scarce, and attention has now turned to an unlikely replacement.

Once dismissed as the "overburden" or "cap seal" that presented an unwelcome interval to be drilled on the way to a reservoir target, clay-rich mudstones ("shale") formations have now become the prey. It has been long-recognized that some dense and very fine-grained shales can store enormous volumes of oil and gas. Provided they are enriched in organic carbon that has been converted to petroleum and natural gas ("source rocks"), and those products have not been expelled into adjacent beds of sandstone or limestone, the opportunity to capture a vast energy supply from shale is enticing. Shales, however, do not give up their prize easily.

The petroleum industry's sudden enthusiasm for shale reservoirs has presented geoscience researchers with unexpected challenges. Despite comprising almost two-thirds of the sedimentary rock record, surprisingly little was known of the fundamental characteristics of shales as recently as 10 years ago. Industry and academic researchers have worked furiously to close this knowledge gap. Employing tools and methods from basic fieldwork to sophisticated scanning electron microscopy, geologists have recorded and interpreted observations from the very large to the very small in order to glean insights into the inner workings of the deceptively complex shales. New models have recently emerged that confront some of the enduring beliefs about how mud is deposited, how it evolves into shale rock and how that rock can store and transmit fluids.

The challenge for oil and gas producers is that the pore spaces that store hydrocarbons between the microscopically small particles comprising shales are so infinitesimally tiny that flow from the rock is effectively nonexistent. Without the benefit of the superhighways of interconnected pores that characterise conventional reservoir rocks, the minuscule droplets of petroleum in shale formations must squeeze their way through a winding maze of narrow corridors and blind alleys. In many cases, the porosity passageways are so narrow that flow is marshalled into queues of individual molecules.

Under special circumstances, nature provides a remedy to this constricted flow in the form of natural fractures. Compared to the shale micropore network, a fracture that appears as a hairline crack to the naked eye is, in fact, a vastly wider artery that connects isolated capillaries and cul-de-sacs into an effective drainage system. Naturally-fractured "tight" reservoirs such as the Austin Chalk in Texas and the Monterey Formation in California can be bountiful producers of oil and natural gas, but natural fractures can be unreliable contributors with uncertain extent and a frustrating tendency to snap shut as formation pressure declines with production. In many instances, natural fractures simply do not develop in organic-rich shale formations because the rock is not sufficiently brittle. In others, fractures have been sealed shut by mineral cements. In either case, without fractures to provide access to the myriad microscopic pores, the oil and gas will remain entombed.

Hydraulic fracture treatments were designed to mimic beneficial natural fractures, but to do so in a targeted and enduring fashion. By pumping highly-pressurized water into the formation, the rock will crack open in a direction dictated by the geology. Sand or ceramic beads are injected into the induced fractures in order to prop them open for the duration of production. Hydraulic fracturing has been in routine use for conventional oil and gas well stimulation since the late 1940s, and proponents point to this long uneventful history as evidence of the safety of the procedure. The design of hydraulic fracture treatments, however, has evolved significantly from the programs used throughout most of that history, and the safety and effectiveness of modern treatments should be evaluated in the context of specific design parameters.

Two characteristics distinguish many of the current fracturing operations from their historical predecessors. First, in order to stimulate flow from a shale reservoir, 10 or more stages of hydraulic fracture treatments are performed along the length of a well drilled horizontally through a target zone. The combination of induced fracturing with long horizontal wells increases the well's contact with the shale reservoir by over 1,000 times.

Secondly, the cumulative volume of water, proppant and additives injected in a multistage treatment program can exceed 10,000 cubic metres. In contrast, a typical conventional fracture treatment requires just 200 cubic metres of fluid.

The commercial development of petroleum and natural gas resources produced from naturally-fractured or hydraulically fractured carbonaceous mudstone reservoirs (colloquially known as "shale oil" and "shale gas") accelerated rapidly in the latter half of the past decade. Buoyed by early success in the prolific Barnett Shale natural gas play of the Fort Worth Basin and the Bakken Shale oil play of North Dakota and Saskatchewan, operators have aggressively developed a growing number of active shale plays in North America (Figure 2).

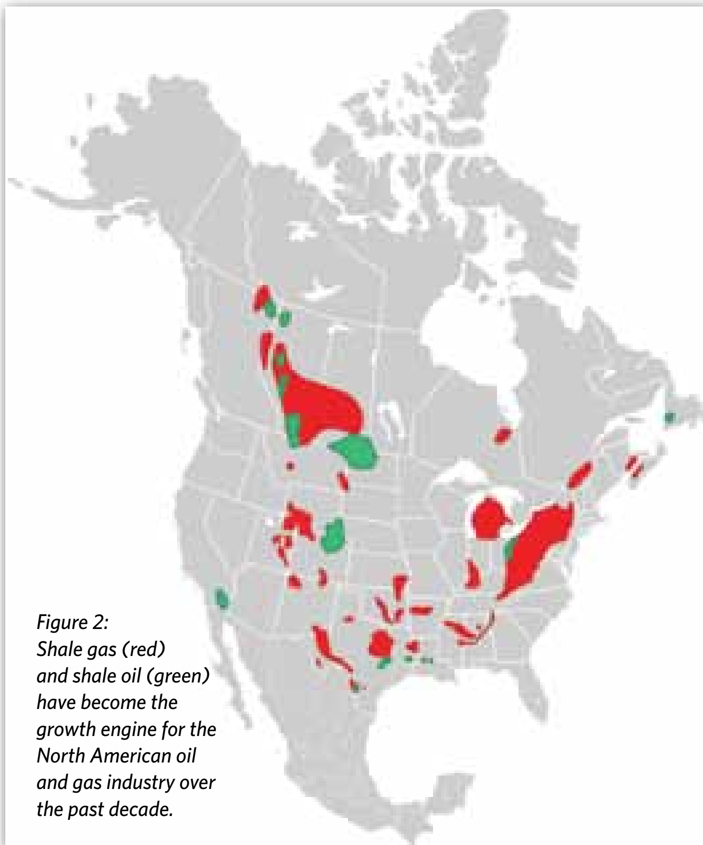


Figure 2: Shale gas (red) and shale oil (green) have become the growth engine for the North American oil and gas industry over the past decade.

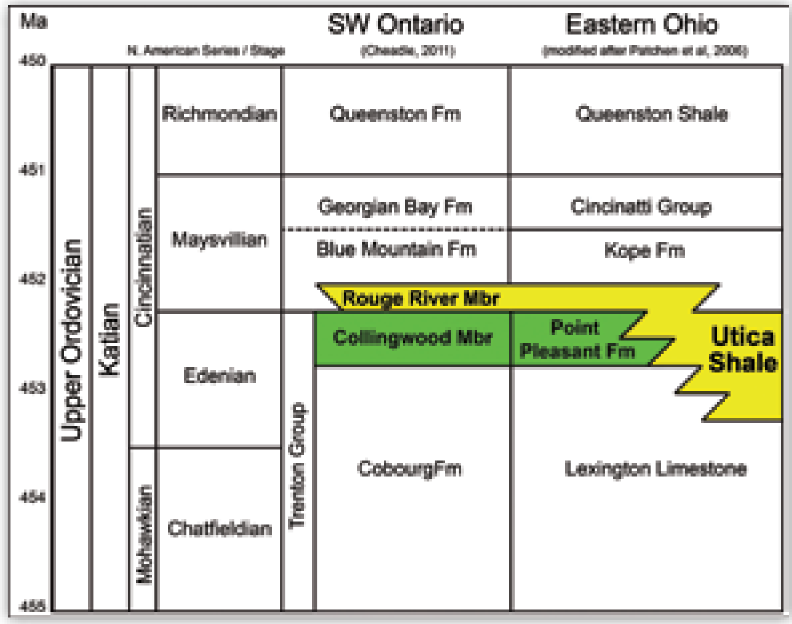


Figure 3: The Utica Shale and Point Pleasant Formation that host eastern Ohio's emerging shale oil play are closely related to source rocks in southwestern Ontario. The Rouge River Member is a local name for the lower petroliferous unit of the Blue Mountain Formation.

Recent successes announced by various operators in the eastern Ohio Utica Shale / Point Pleasant oil play trend raise the possibility that similar oil production potential may extend to related formations in southwestern Ontario (Figure 3). Previous work has confirmed good to excellent source rock characteristics in the Upper Ordovician Collingwood Member and the lower part of the overlying Blue Mountain Formation. Much of the understanding comes from a provincial program to characterise oil shale potential in Ontario during the 1980s, as well as Geological Survey of Canada research programs. The exploration concept that is now under consideration is that some of the more deeply-buried occurrences of these carbon-rich shales in the onshore lands adjacent to Lake Erie may hold oil resources that could be produced using hydraulic fracture treatments of horizontal wells.

A modest degree of enrichment of organic carbon in a shale unit like the Blue Mountain Formation is no assurance of commercial prospectivity. Numerous other geological factors remain to be assessed, including considerations of how much of that carbon has been converted to petroleum, whether the oil has been retained in the shale, and if the rock is amenable to horizontal drilling and hydraulic fracture treatments. These are all fertile ground for new applied research programs that will help communicate the resource potential in the public domain, but they only touch upon one facet of the question. It is in the public interest of Ontario's citizens, regulators and landowners to form a complete understanding of the potential value and costs of developing a new energy resource.

Development of shale-based oil and gas plays has touched off a chorus of concerns regarding the environmental impacts of such activity, particularly in the areas of the U.S. northeast most affected by drilling in the Marcellus and Utica shale gas plays. Peer-reviewed scientific research has been divided on the topic, but public concerns are primarily focused on the potential for groundwater contamination resulting from hydraulic fracturing operations. The lack of baseline information about groundwater conditions prior to drilling and production operations has had the chilling effect of polarising the debate between landowners who claim that contamination has occurred and operators who argue that anomalies are natural background variation.

Applied geological research has much to contribute to an informed conversation about the relative merits of shale oil exploration and development in Ontario. Beyond an objective assessment of the size and quality of the resource, a geological evaluation of the underlying tectonic controls, uncertainties and risks of induced fracture propagation in potential development regions would be a valuable asset for all stakeholders. As a complementary component of a baseline hydrogeological survey, knowledge of the range of possible outcomes of hydraulic fracturing operations could guide project planning, regulatory framework, and landowner consultations toward responsible development decisions.

Today, the dim echo of Oil Springs frenetic beginnings reverberates through a global industry that permeates virtually every aspect of modern life. Discoveries based on ever-evolving geological insights have pushed back exploration frontiers in the relentless quest for energy supplies. Deep below the depleted oil pools that once fuelled the economic growth of a young Ontario lies a new frontier in shales that may hold the promise of reinvigorating North America's oldest oil patch once again. New days bring new expectations, however, compelling geological research to shed light on promise and peril alike. ■

Cambrian Reservoirs of SOUTHWESTERN ONTARIO

BY MICHAEL DORLAND, ONTARIO OIL, GAS & SALT RESOURCES LIBRARY

Introduction

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 km2 (Bailey and Cochrane, 1984), an area slightly less than 50 per cent 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).

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.

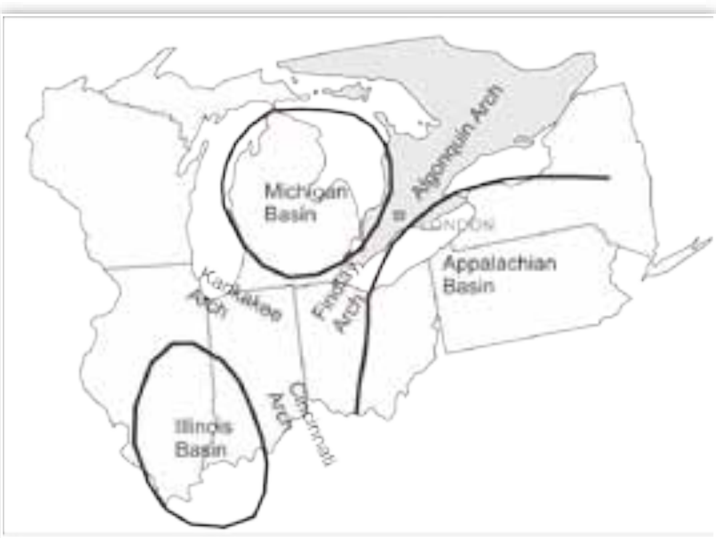


Figure 1. Regional structural setting of southern Ontario (shaded area), showing position of major arches and basins.

Formation Description

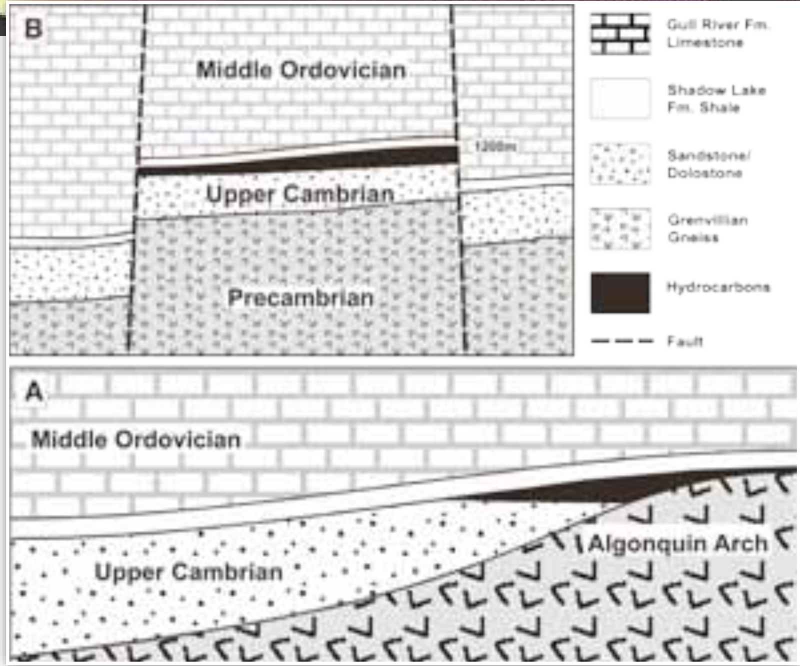
Thickness of the Cambrian section ranges from approximately 175 metres in the centre of Lake Erie to zero metres at the pinch-out edge. In the western part of southwestern Ontario (west of about longitude 81º or approximately London, Ontario) the basal rocks consist of mainly quartz sandstone (Mount 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 81º), 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 and 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

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).

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).



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 kilometres 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.

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; and 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 E6m3 (28 Bcf) from Cambrian gas pools to the end of 2002. Over 89 per cent of the Cambrian gas production has been derived from the Innerkip gas pool, which had a cumulative production of 782 E6m3 (27.6 Bcf) to the end of 2010. 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 per cent of annual Ontario 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. Over 93 per cent of the Cambrian oil production has been derived from three pools. These are the Clearville, Gobles, and Willey pools which had a cumulative production of 820 E3m3 (5.1 MMBO) to the end of 2002.

Reservoir Characteristics

Core analyses show average porosity of 9.2 to 11.8 per cent to a maximum of 20 per cent 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 has 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 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 km2 in southwestern Ontario, but only 1050 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 E6m3 (131.3 MMBO) and 6.3 E9m3 (222 Bcf), respectively. Total potential reserves for the stratigraphic pinch-out edge play are 3.0 E6m3 (19.1 MMBO) oil and 5.1 E9m3 (180 Bcf) gas and for the structural play area 17.9 E6m3 (112.3 MMBO) oil and 1.2 E9m3 (42 Bcf) gas. To the end of 2002, cumulative oil production is 802 E3m3 (5.0 MMBO) and cumulative gas production is 789 E6m3 (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 (personal communication, paper in progress) 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.

References

Bailey Geological Services, and Cochrane, R.O. (1984) Evaluation of the conventional and potential oil and gas reserves of the Cambrian of Ontario. Ontario Geological Survey Open File Report 5499, 72 p.

Burgess, R.J. (1962) Cambrian hydrocarbon traps on the north-west rim of the Appalachian Basin. Proceedings of the 1st Annual Conference of the Ontario Petroleum Institute, 24p.

Dorland, M.J. (2001) Petrography and Diagenesis of Cambro-Ordovician Reservoir Rocks from the Innerkip Gas Pool and Gobles Oil Pool, Southwestern Ontario. Unpublished B.Sc. thesis, University of Western Ontario, 88p.

Harper, D.A., Longstaffe, F.J., Wadleigh, M.A. and McNutt, R.H. (1995) Secondary K-feldspar at the Precambrian-Paleozoic unconformity, southwestern Ontario. Canadian Journal of Earth of Earth Sciences v.32, p. 1432-1450.

Johnson, M.D., Armstrong, D.K., Sanford, B.V., Telford, P.G., and Rutka, M.A. (1992) Paleozoic and Mesozoic geology of Ontario, in Geology of Ontario: Ontario Geological Survey Special Volume 4, Part 2, p. 906-1008.

Pounder, J.A. (1964) Cambrian of Ontario. Proceedings of the 3rd Annual Conference of the Ontario Petroleum Institute, 24p.

Sanford, B.V. and Quillian, R.G. (1959) Subsurface stratigraphy of Upper Cambrian rocks in southwestern Ontario. Geological Survey of Canada, Paper 58-12, 17p.

Sanford, B.V., Thompson, F.J. and McFall, G.H. (1985) Plate Tectonics – a possible controlling mechanism in the development of hydrocarbon traps in southwestern Ontario. Bulletin of Canadian Petroleum Geology v.33, p. 52-71.

Trevail, R.A. (1990) Cambro-Ordovician shallow water sediments, London area, southwestern Ontario. In Geology of Southwestern Ontario, A Core Workshop (ed. T.R.Carter), p.29-51. American Association of Petroleum Geologists, 1990 Eastern Section Meeting, London, Ontario. ■

Middle Ordovician Trenton-Black River Group Carbonate Play in SOUTHWESTERN ONTARIO

BY IAN M. COLQUHOUN, PH.D., P.GEO.

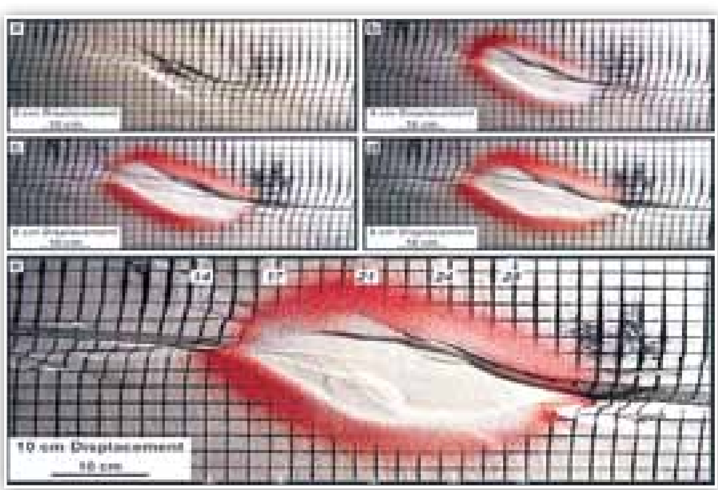
Introduction

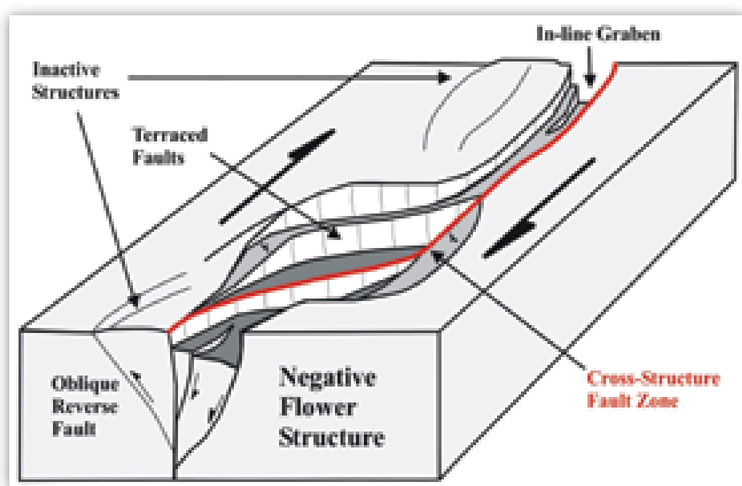
The lower Paleozoic rocks located beneath Essex and Kent Counties within southwestern Ontario have been a focus of exploration for oil and gas over the past few decades. These structurally controlled oil fields are interpreted to have formed within a regional fracture network that provided conduits for fluids that dolomitized the regional limestone, which created 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 kilometres) 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, 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; after Dooley and McClay 1997). Less intense fracturing and dolomitization within relatively bioclastic-poor sediments provided isolated dolomite chimneys or pod-like reservoir development.

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.





Left: 1(a) – Sandbox model with 30o releasing sidestep (Dooley and McClay, 1997).
Right: 1(b) – Isometric representation of a pull-apart basin (Dooley and McClay, 1997).

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 bbls 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 ~14 Bcf of gas and 280,000 bbls 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.

The Northville field was the next Trenton oilfield to be discovered in 1954. 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 lead 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 form 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 eight kilometres east of the Albion Scipio pool, located primarily on the basis of soil-gas geochemistry.

In southwestern Ontario the largest Ordovician oilfield is Goldsmith (6.2 MMbbls) and the largest gas field is Dover (>14 Bcf recovered). The Ordovician play area is approximately 120,000 km2 with an estimated 100 million barrels of oil in place. Only 23 million barrels have been recovered with approximately 40 million barrels recoverable, leaving 17 MMbbls to be discovered. The estimates on gas production are more speculative, but are estimated at 281 Bcf recoverable with only 41 Bcf recovered (Golder Associates 2005).

Total number of wells drilled for Ordovician oil and gas targets in SW Ontario are estimated at ~1700.

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 three weight per cent) to be its 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 (~200 metres thick), a thin cap dolostone atop the Cobourg (one to five 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 metres) 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-upwards 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 (Aigner 1985). 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 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 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 SW 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 (Aigner 1985 and 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 SW 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 (~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 (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 >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 enhance 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 (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 per cent, irreducible water saturation commonly ranges between 15 and 25 per cent. 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 SW Ontario, the first has a prominent NW-SE trend and the second has a prominent W-E trend. The main characteristics of the NW-SE trend include more pervasive dolomitization throughout both Trenton and Black River group carbonates, oil reservoir in 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 Sherman Fall Bioclastic (Trenton), dual reservoir potential with gas in Sherman Fall Bioclastic and oil in the Coboconk Formation, and a pod-like reservoir where dolomite chimneys are commonly isolated.

In constructing a dolomitization model for a thick sequence of carbonates, which is overlain by a relatively thick sequence of marine shales and sediments, the question of subaerial or submarine exposure has major implications for the model of dolomitization and reservoir development. There is no evidence of subaerial exposure for Trenton Group carbonates (Wilman and Kolata, 1978; Fara and Keith, 1984) with the possible exception of sediments in the Albion-Scipio area of southern Michigan. Lack of subaerial exposure in southwestern Ontario implies that meteoric fluids had little to do with early burial diagenesis or early dolomitization of the limestones. Major, minor and trace element data and stable isotope compositions of the carbonates demonstrated that meteoric fluids were not present during dolomitization of the precursor limestone.

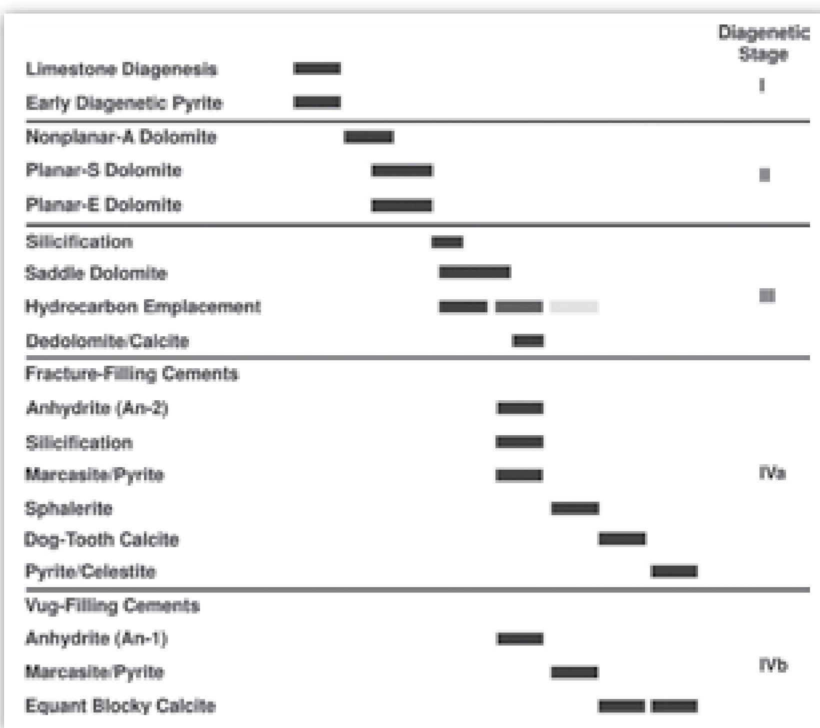
Interpretation of the paragenetic history of the rocks and an interpretation of the structural framework of these reservoirs has provided a basis for a reservoir development model that best describes the reservoir character encountered during drilling operations for hydrocarbons.

A structural development model was proposed by Colquhoun and

Johnston (2004) using detailed 3-D and 2-D seismic data over the Dover 7-5-VE oil field. A modified version of this structural development model is proposed in this article for Ordovician reservoirs within Essex and Kent counties of southwestern Ontario. The features within the structural model are proposed to be the result of wrench faulting from extensional tectonics. Within southwestern Ontario extensional faulting occurred as early as Upper Ordovician and was active up to Middle Devonian time, therefore includes tectonic adjustments during both Taconic and Appalachian orogenies. The resultant sinistral shearing most likely occurred in several stages and the following series of diagrams summarize the evolution of structure and fluid migration during major stages, including hydrothermal dolomitization and reservoir creation, hydrothermal alteration and hydrocarbon emplacement, and continued tectonic adjustments and evolution of formation waters coincident with latest shearing events.

Stage 1: Dolomitization

Structural development of Ordovician lows is interpreted to be the result of wrench-faulting from extensional tectonics. Within southwestern Ontario extensional faulting occurred as early as upper Ordovician and was active up to middle Devonian time, and therefore includes tectonic adjustments during both the Taconic and Appalachian orogenies. The resultant sinistral shearing must have occurred in stages. This interpretation is supported in part by extensive geochemical evaluation of the host rocks, secondary minerals, and produced fluids and the burial history modeling of the rocks within southwestern Ontario (Colquhoun, 1991) that also suggest a succession of events lead to the creation and alteration of these reservoirs.



The first stage includes dolomitization of the host limestone and creation of the reservoir, or at least a major part of it, by warm basinal fluids. These warm fluids migrated through the Cambrian sandstones by hydrostatic pressures influenced by basinal circulation of brines, up along faults and fractures into the overlaying carbonates and progressively dolomitized the limestone. Dolomitization occurred along the faults and fractures but also along preferred pathways within porous bioclastic-rich carbonates. Dolomitization likely occurred prior to maximum subsidence of the basin (>300 Ma) and during initial development of the pull-apart structures during upper Ordovician time ~440 mya.

Stage 2: Hydrothermal Alteration and Hydrocarbon Emplacement

During successive tectonic adjustments progressive shearing created larger and broader structures predicted by analogue modeling such as Dooley and McClay (1997). This was likely coincident with the migration of hot basinal brines into the Ordovician sediments that were responsible for hydrocarbon migration and emplacement, perhaps including hydrocarbon maturation, followed by cementation within the faults and fractures by saddle dolomite (HTD), calcite (HTC) and high temperature quartz. Cementation within the faults and fractures and the creation of localized breccia zones within the section effectively sealed the reservoir at the end of stage 2.

Geochemical evaluation of the rocks supports the concept that hydrothermal fluids followed the earlier dolomitization event that created the reservoirs (Colquhoun 1991). This allowed the migration of gas into the Sherman Fall Bioclastic and oil within the Coboconk Formation resulting in stacked reservoirs in some places and segregated reservoirs in others. However, there have been occurrences of both gas and oil in the same reservoir.

The timing of this event was estimated using Lopatin basin modeling techniques to be ~250 Ma or during late Permian (Colquhoun 1991). Several tectonic events occurred over a short time frame including a structural overprinting event during Pennsylvanian time. This occurred during later stages of the Appalachian Orogeny throughout southwestern Ontario and Michigan as a result of the progressive formation of Pangaea ~300 mya. The event is observed as the collision between Gondwana and Laurasia that led to the formation of the Appalachian belt in North America. Later tectonic adjustments occurred during late Permian time coincident with the creation of the super continent Pangaea around 250 mya. Paleomagnetic and rock magnetic analysis (Garner, 2006) estimated a subsequent remagnetization date for the dolomitization event between Late Paleozoic and Early Mesozoic, or from 265 to 240 Ma. The structural events provided the push and hydrostatic conditions necessary for regional fluid migration to occur but the second critical component is the source of heat, sediment burial is important but an external or additional source is required to provide hot fluids at shallow burial depths within southwestern Ontario.

Approximately 252.6 million years ago the largest extinction event in geologic history occurred and is recorded in rocks in Siberia. A total of 1.6 million square kilometers of fiery, gassy lava erupted across Siberia, an event so massive that the new timing points a finger at extinction. High precision 40Ar/39Ar data confirms that the West Siberian Basin basalts, located west of the Siberian Traps, are actually part of the Siberian Traps and therefore at least double the confirmed area of the volcanic province as a whole (Reichow et al, 2002). These results strengthen the link between the Siberian flood basalts and the end Permian crisis.

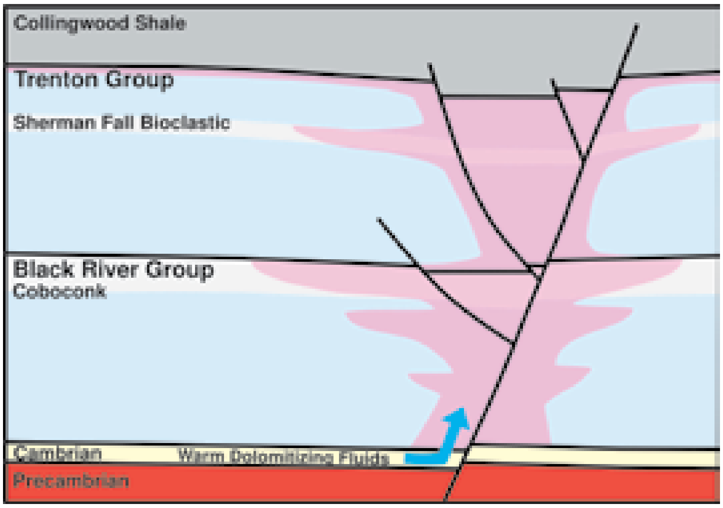
It has been suggested that a huge meteorite or comet plunged into the northwest coast of Australia and was responsible for triggering the Siberian volcanism. Such a significant heat source would be necessary to create the conditions that led to hydrothermal mineralization within the shallow Ordovician rocks of southwestern Ontario, which experienced temperatures of alteration similar to those estimated for Ordovician rocks at much deeper depths in Michigan and Appalachian Basins. A single mechanism for heat generation is required to affect such an extensive area and possibly including large areas across North America that experienced hydrothermal alteration around the same time. It is proposed that mantle plumes may have also concentrated at depth along the borders of the North American plate with the European and African plates that previously created the Appalachian Mountains. This was the future site where mantle convection would have concentrated to begin separation of the plates during the breakup of the super continent known as Pangaea.

Stage 3: Evolution of Fluid and Structure

During later stages of tectonic adjustment the diagenetic seal became partially breached and rejuvenated and/or newly formed faults and fractures developed lower within the structures allowing formation waters and hydrocarbons to migrate into higher stratigraphic positions around the main reservoir. These evolved formation waters were no longer saturated with respect to dolomite or limestone and therefore had the ability to dissolve rock and create cavernous porosity or extensive lost circulation zones. These porous zones occurred along the edges of the reservoir and contain formation water but in some cases also contain hydrocarbons. The timing of this last stage is currently unknown but occurred during later stages of basin unloading and cooling).

Exploration Methods

Surface reconnaissance methods that are good indicators of physicochemical processes related to hydrocarbon oxidation from near surface hydrocarbon migration includes 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 can't 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.

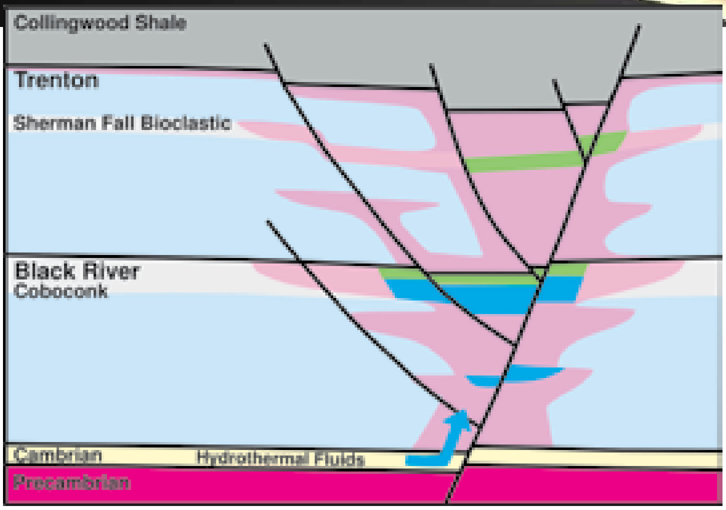
Current Exploration and Development

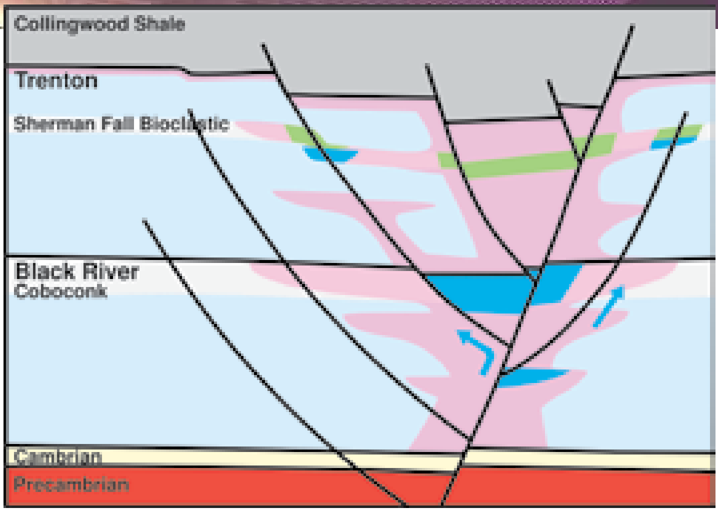
Drilling in the Ordovician play by Consumers' Gas, Pembina Exploration, Ram Petroleum and Paragon Petroleum Corporation (and its predecessors) during the 80s and 90s boasted up to 67 per cent success for exploration wells and over 80 per cent for development wells. Their successor, Talisman Energy, posted development success numbers above 90 per cent. Dundee Energy LLP acquired Talisman's Ontario assets in 2010 and is the current operator of the majority of Ordovician oil pools in southwestern Ontario.

Future Exploration Areas

In order to assess 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. It is recommended to explore east of Kent County along the north shore of Lake Erie and on the south side of the Algonquin Arch where Cambrian sandstones are present.

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 of these criteria are important to determine if reservoir creation and hydrocarbon migration was possible within a new play area.

There is a modest to strong correlation between magnetic highs and the location of HTD reservoirs in the middle Ordovician carbonates of SW Ontario. It is recommended to use high resolution magnetic surveys (HRAM) and lineament analysis as a first order exploration method to identify areas that are prospective for HTD reservoirs prior to shooting 2-D seismic surveys. Lineament analyses of HRAM data over existing Trenton-Black River pools in southwestern Ontario can be used to identify the magnetic and structural characteristics associated with HTD reservoirs. Lineament analysis should be used to identify structures that appear similar to the analogue pools. Successful identification of predominant fault orientations and the presence of linear trends should be followed up with 2-D seismic surveys to confirm the presence of a wrench fault-generated sag structure. It is recommended to drill an exploratory well to confirm the presence of oil and gas reservoir in the Trenton and/or Black River Group carbonate rocks. Successful exploratory drilling should be followed up with a 3-D seismic survey over the entire linear trend defined on 2-D seismic to delineate the location and size of reservoir pods located within the pool boundaries prior to extensive development drilling and production facility construction.

References

Aigner, T. (1985). Storm depositional systems: Dynamic stratigraphy in modern and ancient shallow marine sequences; Lecture Notes in Earth Sciences, 3, Springer-Verlag, Berlin, 174p.

Bownocker, J.A. (1903). The occurrence and exploitation of petroleum and natural gas in Ohio; Geological Survey of Ohio, 4th series, Bulletin 1, 325p.

Brett, C.E., and Brookfield, M.E. (1984). Morphology, faunas and genesis of Ordovician hardgrounds from southern Ontario, Canada; Palaeogeography, Palaeoclimatology, Palaeoecology, 46, p. 233-290.

Burgess, R.J. (1960). Eastern Canada has a new exploratory target...oil in Trenton synclines; Oil and Gas Journal, 58, No. 33, p. 124-131.

Caprarotta, D.W., Schrider, L.A., Natoli, M.A., and Sawyer, W.K. (1988). A case study for exploration and development of the Trenton reservoir in northwest Ohio; in B.D. Keith (ed.), The Trenton Group (Upper Ordovician Series) of Eastern North America, American Association of Petroleum Geologists, Studies in Geology #29, p. 191-205.

Colquhoun, I.M. (1991). Paragenetic history of the Ordovician Trenton Group carbonates, southwestern Ontario; Unpublished M.Sc. thesis, Brock University, 250p.

Colquhoun, I.M. (2001). Carbonate cores of the Middle Ordovician Trenton and Black River Groups of Southwestern Ontario; OPI 40th Annual Conference, London, ON, November 17, 2001, CD.

Colquhoun, I.M. and Johnston, H.P. (2004). A comprehensive evaluation of the Dover 7-5-VE Trenton-Black River field. In: Ontario Petroleum Institute Forth-Third Annual Conference, Ontario-New York Oil and Gas Conference, November 8-10, 2004, v. 43, Technical Paper No. 16, 15p.

Dooley, T. and McClay, K. (1997). Analogue modeling of pull-apart basins. American Association of Petroleum Geologists Bulletin, v. 81, p. 1804-1826.

Fara, D.R. and Keith, B.D. (1984). Depositional facies and diagenetic history of Trenton limestone in northern Indiana (Abstract), American Association of Petroleum Geologists, Bulletin, v. 68, p. 1919.

Garner, N. (2006). Magnetizations of Ordovician petroleum reservoir rocks, southwestern Ontario: Unpublished M.Sc. thesis, University of Windsor, 113p.

Golder Associates Ltd. (2005). Hydrocarbon resource assessment of the Trenton-Black River Hydrothermal Dolomite Play in Ontario; Ontario Oil, Gas, and Salt Resources Library, 35 pages, 27 figures, 8 tables, 11 cross-sections, 7 pool maps, 4 appendices.

Keith, B.D. (1985). Facies, diagenesis and the upper contact of the Trenton limestone of northern Indiana; in R. Cercone and J.M. Budai (eds) Ordovician and Silurian Rocks of the Michigan Basin, Michigan Basin Geological Society Symposium, Special Paper 4, p. 15-32.

Kobluk, D.R., and Brookfield, M.E. (1982). Lower Paleozoic carbonate rocks and paleoenvironments in southern Ontario; IAS, Eleventh International Congress on Sedimentology, Excursion Guidebook 12A, 62 p.

Landes, K.K. (1970). Petroleum geology of the United States; Wiley-Interscience, New York, 571 p.

Reichow, M.K. et al. (2002). 40Ar/39Ar Dates from the West Siberian Basin: Siberian Flood Basalt Province Doubled. Science 296, p. 1846.

Sanford, B.V. (1961). Subsurface stratigraphy of Ordovician rocks in southwestern Ontario; Geological Survey of Canada, Paper 60-26, 54 p.

Wilman, H.B. and Kolata, D.R. (1978). The Platteville and Galena groups in northern Illinois. Illinois state Geological Survey Circular 502, 75p. ■

Lower Silurian Sandstone Reservoirs of SOUTHWESTERN ONTARIO

BY M. MOLGAT, TALISMAN ENERGY INC.

Introduction

Lower Silurian Whirlpool, Grimsby and Thorold sandstone reservoirs form one of the most significant gas plays in the Appalachian Basin. The play spans a large area of 700 kilometres in length by 200 kilometres in width extending from northeastern Kentucky, into Ohio, Lake Erie, southwestern Ontario, northwestern Pennsylvania, to western New York. These sandstones have been and continue to be economically important gas reservoirs in southwestern Ontario. They have accounted for about 46 per cent of total Ontario gas production in the past decade, producing over 2.3 billion cubic meters (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. The trapping mechanism is primarily stratigraphic. Gas productivity appears to be related to porosity and permeability variations caused by clay content, diagenetic histories, and, on a basin-wide scale, burial depths. Burial depth of productive reservoirs in Ontario ranges from 60 meters in Niagara County to 625 meters in Central Lake Erie.

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 Whirpool Formation disconformably overlies red marine siltstones and shales of the Upper Ordovician Queenston Formation and is conformably overlain by argillaceous, fossiliferous dolomites of the Manitoulin Formation in Central Lake Erie and marine shales of the Cabot Head Formation in East Lake Erie. 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 white to grey in colour 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 ranging from nine to zero meters, generally thinning and pinching out to the north and northwest where it becomes transitional with dolomites of the Manitoulin Formation.

The Grimsby Formation, also referred to as the Clinton sandstone as a result of miscorrelations that took place during the early development of the play, overlies marine shales of the Cabot Head Formation. In Ontario, the contact 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, large-scale cross-stratified, quartzose sandstones with common mud couplets. Sandstones are commonly white in colour. 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 are commonly red in colour. Deposits of the upper unit are interpreted to represent discrete tidal channels and associated mud flats (Benincasa et al., 1997). It is important to note that colour 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., 1991). As such, changes in colour are diagenetic in origin and do not correspond to unit boundaries.

Grimsby thickness ranges from zero to twenty meters. Thickest sections are located near the international border in East and Central Lake Erie. The Grimsby thickens south of the border and generally thins to the west and north where it passes laterally into shales of the Cabot Head Formation.

The Thorold Formation is also known as the "Stray Clinton" and overlies the Grimsby Formation. It is generally composed of finer grain sediment and is also typically more highly bioturbated than the Grimsby Formation. Lithologically, it is composed of very fine quartzose sandstone interbedded with shale 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 its sediments to have been derived from reworked Grimsby deposits (Sanford, 1969). It reaches a maximum thickness of six metres and is mainly distributed in Haldimand-Norfolk counties and in parts of East and Central Lake Erie.

Reservoir Characteristics

Lower Silurian reservoir characteristics are highly variable. Pay thickness is generally thin and commonly vertically discontinuous, ranging from 0.5 to a total of 15 net metres. Porosity ranges from two to 18 per cent. Producing wells generally have values greater than eight per cent and are generally non-economic below this. Similarly, permeability varies greatly, ranging from 0.1 to 100 millidarcies. Better reservoirs typically have values over five millidarcies. Water saturations also vary significantly from pool to pool, ranging from 15 per cent to over 85 per cent. Gas-water contacts, where present, are observed at different structural levels, which reflects the laterally discontinuous nature of these reservoirs. The producing wells from sandstones in Lake Erie have estimated production of up to 85 million m3 of natural gas (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 (Overbay and Henniger, 1971). The principal 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.

Good reservoirs that have a cumulative production greater than 8.5 million m3 (>0.3 Bcf) seem to 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 along the north flank of the East Ohio fault system where best Cataract production is located on “upthrown” blocks that parallel the fault system (McCormac et al, 1996), and in Whirlpool reservoirs of East Lake Erie, which also appear to be linear.

In Ontario, Lower Silurian reservoirs are sweet gas reservoirs 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/m3 (1084.3 BTU/ft3). Whirlpool, Grimsby, and Thorold gas production is commonly commingled.

Ontario 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 and the discovery of all of the large onshore pools in Niagara, Haldimand, Norfolk, and Brant Counties by 1910. Despite having over a century of drilling history, the development and extension of these pools continues to this day. Cumulative gas production from onshore pools to the end of 1994 was 6.5E^9m^3(231 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 large Lake Erie sweet gas pools were discovered. Offshore seismic programs commenced in 1968. Presently, over 8,000 kilometres (5000+ miles) of two-dimensional seismic lines have been acquired. Drilling activities, number of operating companies, number of drilling rigs, and production, peaked in the mid 1980s. Today, only one operator is actively pursuing the Silurian sandstone play in Lake Erie. Cumulative gas production from the offshore pools to the end of 1994 was 5.4E^9m^3(191Bcf). It should be noted that regulators in the province of 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. However, seismic data is of little use to delineate channels or abundance of sandstone in most parts of Southwestern Ontario because of poor data quality. Locally, seismic data has been used to delineate structural highs interpreted to be potential traps. This method of exploration had mediocre success.

Almost all of Ontario wells that target the sandstones are vertical wells. There were only three attempts at drilling horizontal wells in the sandstones in Lake Erie, with no improvements in productivity. Directional wells are also drilled in Ohio to avoid residential areas and environmentally sensitive areas like wetlands (Mc Cormac et al., 1996).

Current Exploration and Development

There was a major rejuvenation of interest and drilling activities for onshore Lower Silurian gas 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

WELL PRODUCTIVITY	WHIRLPOOL & GRIMSBY
Present average production (~ 500 offshore wells)	47 mcf/d
First year average production (1996-2000)	370 mcf/d
First year decline	40%
Second year decline	25%
Long term decline	8%

Table 1. Average flow rate and declines for offshore sweet gas well. Modified from Gordon and Brame, 2000

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, 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 lower Silurian gas in Lake Erie has been in a lull since 2000 as the preferred target over the past few years has been Guelph reservoirs. Interest in offshore Lower Silurian gas 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 (Bailey and Cochrane, 1986). The offshore portion accounted for about 96 per cent of the total, while onshore areas accounted for just over three per cent, mostly in Norfolk and Haldimand townships. Onshore gas exploration is limited due to extensive drilling of pools during in past century, high recovery factors of >95 per cent, and close spacing between well (10 to 40 hectares or 25 to 100 acres) (Cochrane et al, 1986). Conversely, offshore spacing is more typically 255 hectares (640 acres), recovery factors are estimated at 15 per cent and many tracts have not been drilled or properly evaluated. Therefore, it is clear the best area for future exploration and development activities lies 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.

References

Benincasa, A.J., 1996. Sedimentology and Stratigraphy of the Lower Silurian Grimsby Formation, in Subsurface, Lake Erie and Southwestern Ontario. Unpublished M.S. thesis, Brock University, 218 p.

Benincasa, A.J., and Cheel, R.J., 1997. Sedimentology and Stratigraphy of the Lower Silurian Grimsby Formation. In: Subsurface, Lake Erie and Southwestern Ontario. Ontario Petroleum Institute. V. 36.

Johnson, M.F., 1998. The Sedimentology of the Lower Silurian Whirlpool Sandstone, in Subsurface Lake Erie, Ontario. Unpublished M.S. thesis, Brock University, 186 p.

McCormac, M.P., Mychkovsky, G.O., Opritza, S.T., Riley, R.A., Wolfe, M.E., Larsen, G.E., and Baranoski, M.T., Ohio Department of Natural Resources, 1996, Play Scm: Lower Silurian Cataract/Medina Group ("Clinton") Sandstone Play in the Atlas of Major Appalachian Gas Plays, John Roen and Brian Walker eds, West Virginia Geological and Economic Survey. p. 156 - 163

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

Sanford, B.V., 1969. Silurian of southwestern Ontario. Ontario Petroleum Institute Journal, vol. 8, no. 5.

Zagorski, W.A., 1991. Model of local and regional traps in the Lower Silurian Medina Sandstone Group Cooperston gas field, Crawford and Venango counties, Pennsylvania: Unpublished M.S. thesis, University of Pittsburg, 131 p. ■

Reservoirs and Production from the Silurian Carbonate Rocks of SOUTHWESTERN ONTARIO

BY R.O. COCHRANE, CAIRNLINS RESOURCES LIMITED

Introduction

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 which is overlain by lime muds which are dark grey to black at the base becoming lighter in colour at the top of the unit. In many localities, the top 5 to 10 metres of the A-1 was deposited in a shallow tidal flat and has beds of light to medium brown dolomite interspersed with anhydrite. These beds have secondary porosity which 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 0 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 upwards to light to medium brown sucrosic dolomite interspersed with anhydrite beds at the top. The thickness of the dolomite unit varies from 3 to 10 metres. The A-2 Unit is overlain by halite of the Salina B Salt; 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

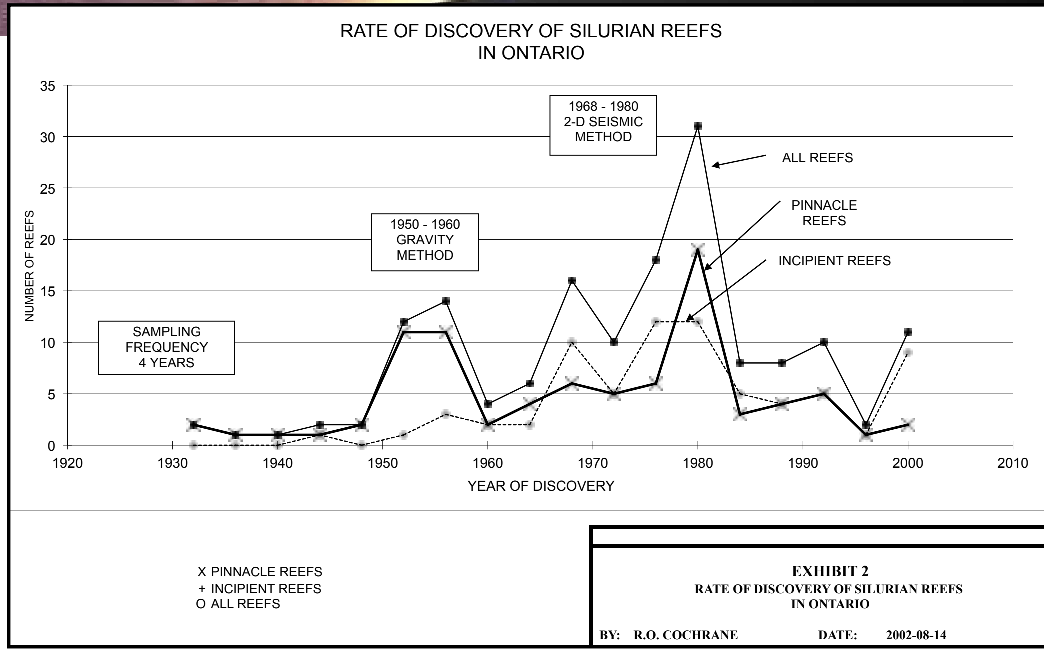
Stratigraphic traps in the Silurian carbonates are of two types: reefs and porous lenses controlled by facies variations.

The primary porosity in the reef mounds is enhanced by dolomitization and episodal karsting during and following reef development; 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 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 which 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 is 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 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 Townships 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 8 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 which 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 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 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.

References

Bailey, S.M.B., 1986: "A New Look at the Development, Configuration and Trapping Mechanisms of the Silurian Guelph Reefs of Southwestern Ontario." Ontario Petroleum Institute Twenty-Fifth Annual OPI Conference Volume 25 No.16

Bailey Geological and Cochrane, R.O., 1990: Geology of Selected Oil and Gas Pools in the Silurian Carbonates of Southern Ontario; Ontario Geological Survey, Open File Report 5722, 50p.

Bailey, S.M.B., 2002: The Geological Implications of Some 3-D "Fishnet" Seismic Images of Guelph Pinnacle Reefs in Ontario: A Different Perspective on their Growth, Destruction and Complexity." Ontario Petroleum Institute Forty-First Annual OPI Conference Volume 41 No.15

Carter, T.R., 2003: "Oil and Gas Exploration and Development Activity in Ontario in 2002" OPI Newsletter, April 2003.

Druet, Paul, 2002: Horizontal Drilling in the Black Creek Storage Pool: A Success Story.

Ontario Petroleum Institute Forty-First Annual OPI Conference Volume 41 No.18

Koepke W.E. and Sanford B.V.,1965: The Silurian Oil and Gas Fields of Southwestern Ontario Geological Survey of Canada Paper 65-30

Oil Gas and Salt Resources Library, 2001: "Oil and Gas Pools and Pipelines of Southern Ontario, Version June1, 2001

Oil Gas and Salt Resources Library, 2002:"1989 to 2000 Summary, Oil and Natural Gas Exploration, Underground Storage and Solution Mining in Ontario" Oil Gas and Salt Resources Library, London, Ontario. ■

Middle Devonian Reservoirs of SOUTHWESTERN ONTARIO

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Introduction

The Middle Devonian Lucas and Dundee formations of Ontario have produced approximately 45 million barrels of oil (MMBO), which equates to approximately 50 per cent of Ontario's oil production to date. The first oil discovered in North America was from the shallow Middle Devonian carbonates in 1858 at Oil Springs, Ontario. One hundred and fifty-five years later some of these early discoveries are still producing today. Three of the largest oil fields in Ontario are Middle Devonian in age and include Petrolia (18.5 MMBO), Rodney (10.7 MMBO) and Oil Springs (10.3 MMBO). Bothwell-Thamesville (3.3 MMBO) and Glencoe (1.1 MMBO) were also very significant discoveries. The Middle Devonian reservoirs therefore, historically have been a very economically important hydrocarbon play.

Early exploration methods included drilling surface seeps, the use of dowsers, psychics and rudimentary geological mapping. A number of modern techniques which 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 – 500 feet or 120-150 meters), high-gravity oil (38 API), relatively high yields (eight – 10,000 barrels/acre) and long productive life-span. 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). In the 1900s there were three significant discoveries Glencoe (1917), Watford-Kerwood (1938) and the Rodney Pool in 1949 (Table 1). Of these seven significant early discoveries four are still on production today.

The past 20 years have seen the drilling of approximately 50 wells directed to Middle Devonian targets and have resulted in the discovery of 10 new infill producers in the Rodney pool, 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 10 producing wells of which three are horizontal completions. 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 45 MMBO out of a total of 90 MMBO produced in Ontario to the end of 2010. Devonian oil production in 2010 amounted to 111,347 barrels or approximately 21 per cent of the total production for the year as compared to 41.3 per cent 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.

POOL NAME	DISCOVERY YEAR	CUMMULATIVE PRODUCTION (BARRELS)	ACTIVE
Oil Springs	1858	10,323,000	Yes
Petrolia	1862	18,598,000	Yes
Bothwell-Thamesville	1862	3,329,000	Yes
Wallacetown	1898	253,000	No
Glencoe	1917	1,139,000	No
Watford-Kerwood	1938	132,000	No
Rodney	1949	10,713,000	Yes

Table 1. Major Middle Devonian Oil Pools (Cumulative production current to 2010 incl., rounded to nearest 1000)

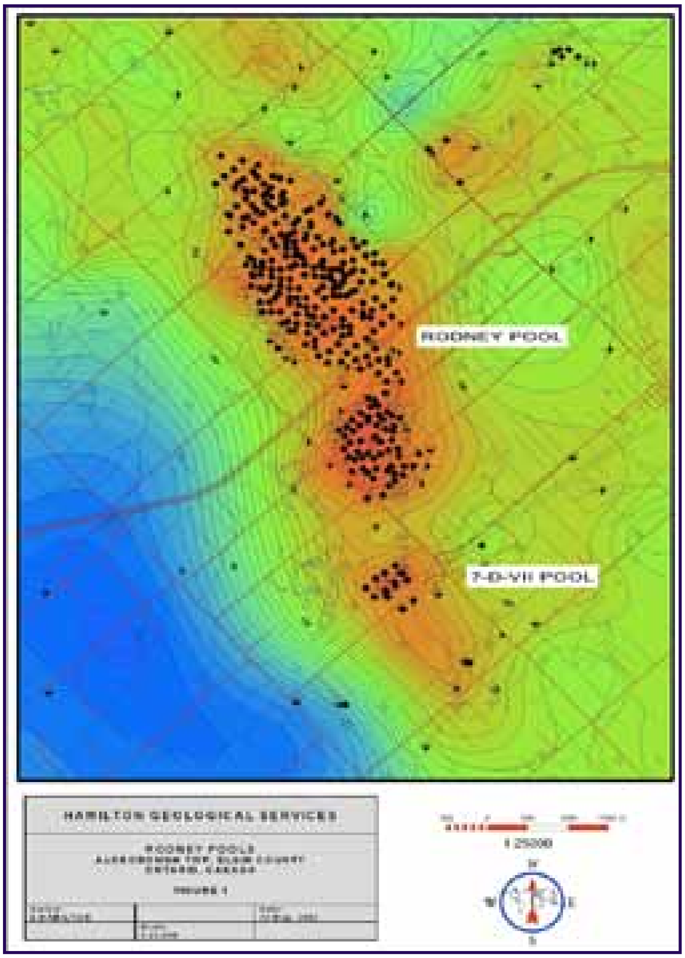

Figure 1 Structure Top of Dundee Formation
Contour interval = 3 metres

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 per cent and permeability of five to 430 mD. The sandstone unit is the producing reservoir in the Glencoe pool where porosity ranges from 10 to 21per cent 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 Columbus zone is a siliclastic-rich dolomitized limestone with porosity commonly in the 12 to 30 per cent 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 is one of the best examples to illustrate 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. 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 per cent increase in daily production volumes and to date approximately 55 per cent recovery of the estimated original oil in place. After 60 years of production Rodney is still producing approximately 80 BOPD with a decline rate of less than five per cent.

The 7-D-VII pool was initially defined using a combination of computer geological mapping, gravity, magnetics and petrophysical analysis. Two dimensional seismic (2D) 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 fifty years but there remains 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 seismic 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. ■