EPEX 2018

Energy Prospectors Expo

Ontario Petroleum Institute 56th Annual Conference and Trade Show

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What is EPEX?

EPEX highlights the multifaceted nature of Ontario's oil, natural gas and salt Industries and how they fit into Ontario's energy landscape. EPEX identifies opportunities to help other energy sectors. After all, we're all doing the same thing but in different ways -- and that is why the OPI and OGSR Library wanted to bring everyone together.

Each one of you is an important collaborator in this conference and your participation highlights the multidimensionality of our energy sector in Ontario.

The EPEX logo is a tesseract, a four-dimensional shape with 24 faces, chosen to represent the complexities and multiple layers of energy production in Ontario.

EPEX is about more than prospects – it's about exploring.

Join us in the plenary session and let's start exploring our collaborative energy future!

Social Media #epex2018

We're live online. Follow the conference, post picture and ask questions on twitter using the hashtag:

#epex2018

Let's see your favourite conference photo!

Schedule of Events

EPEX 2018: OPI's 56th Annual Conference

Monday, May 14th

Length	*Time*	*Event*	*Presenters*
4 hr	**12:00**	Booth Set-up	
1 hr	**4:00**	Energy Collaboration Showcase	OPI, MNRF, OGSR Library
3 hr	**5:00**	**Icebreaker**	

Tuesday, May 15th

Length	*Time*	*Event*	*Presenters*
60 min	**7:00**	Breakfast	
		Poster Set-up	
15 min	**8:15**	Official Conference Opening	Ian Colquhoun
45 min	**8:30**	**Plenary**	Maia Somers, MC; Ian Colquhoun, Conference Chair; Hugh Moran, OPI; Jordan Clark, OGSR Library
30 min	9:15	Morning Coffee Break and Poster Judging	
		BLOCK 1: ENERGY STORAGE	
		CO-MODERATORS: CHELSEA UNGAR, ELISHA PERSAUD	
20 min	**9:45**	Hydrocarbon Storage in Porous Rock Reservoirs and Salt Solution Mined Caverns in Ontario	Jug Manocha, Petroleum Operations Section, Ministry of Natural Resources and Forestry
20 min	**10:05**	Natural Gas Storage – The Dawn Hub	Michael Learn, Union Gas Limited
20 min	**10:25**	Compressed Air Energy Storage (CAES)	Eric Tharumalingam, University of Waterloo
20 min	**10:45**	Underground Energy Storage in Porous Reservoirs in Ontario	David Thompson, Northern Cross Energy Limited
15 min	**11:05**	**BLOCK 1 PANEL DISCUSION**	
15 min	11:20	Intersession Break	

Duration	Time	Session	Speaker
		BLOCK 2: ENVIRONMENT AND RISK MANAGEMENT	
		MODERATOR: ELISHA PERSAUD	
20 min	**11:35**	History, mandate and operations of the Indian Oil and Gas Canada organization	Shawn Williams, Indian Oil and Gas Canada
20 min	**11:55**	Omaha! A Pundits Playbook to In-Situ Remediation of PHCs	Gary Winthrop, Matrix Solutions Inc.
15 min	**12:15**	**BLOCK 2 PANEL DISCUSION**	
90 min	12:30	Lunch Break	
	1:00	**Keynote Speaker**	Teri Kirk, President & CEO, Fundingportal
10 min	1:45	**Student Poster Awards**	
		BLOCK 3: HYDROCARBONS	
		MODERATOR: CHELSEA UNGAR	
20 min	**2:00**	The Ontario Opportunity - A Basin-Entry Perspective	Laurent de Verteuil, Mundo Nuevo Limited
20 min	**2:20**	A Geochemical Approach for Tracing Leaking Well Fluids in Southwestern Ontario	Fred Longstaffe, The University of Western Ontario
20 min	**2:40**	Gedex High Definition Airborne Gravity Gradiometer - Potential for SW Ontario	Brian Main, Gedex Systems Inc.
15 min	**3:00**	**BLOCK 3 PANEL DISCUSION**	
	3:15	Afternoon Coffee Break	
		WORKSHOPS	
45 min	**3:30**	Building a Regional 3-D Geologic Model of the Paleozoic Bedrock	Terry Carter, Carter Geologic; Liz Sutherland, OGSR Library
		Tours and Cores	Maia Somers, OGSR Library
10 min	4:15	Closing Remarks - Wine and Cheese Start	
2 hrs	5:00	Exhibit Hall Closes - Booth Tear-down	
3 hrs	7:00	**Brewery Tour & Networking**	London Brewing Co-Op (521 Burbrook Pl)

OPI 56th Conference Opening Remarks

OPI President's Remarks

I would like to welcome all of our guests and members to EPEX 2018, the 56th Annual Ontario Petroleum Institute Conference and Trade Show.

I would like to thank the Conference organizing committee chaired Ian Colquhoun, Hugh Moran, and Lorraine Fillmore from the OPI office, and the Library staff for putting together this year's agenda.

Thanks to all of the speakers taking part in the sessions. A special thank you to keynote speaker Teri Kirk.

Thanks also to the vendors that are taking the time to show their products and manning their booths. Please take the time to stop by and visit with them.

Oil and natural gas are commodities that have been part of the Ontario economy since 1858, and will be for many years to come. The last few years haven't been necessarily easy for any of us in the exploration and production end of the industry. Despite the challenges things are looking up. Prices have been rising steadily in recent months, the world supply of oil has declined and the future looks more promising.

We hope you enjoy the 56th Annual Ontario Petroleum Institute Conference and Trade Show.

Thank you for attending.

Dale Holland, President

Ontario Petroleum Institute

Conference Chair's Remarks

The OPI conference is a time for all oil and gas industry people, direct or indirectly related to the industry to come together and share knowledge and update each other on our business activities. The idea of collaboration is not a new one, but it is one that has been on hold in recent years. The OPI conference provides a time, place and an opportunity for people to share their experiences and knowledge on an annual basis with each other towards the one goal that we all have, to get back to work in the oil and gas industry here in SW Ontario, find economic oil and gas deposits, and work on energy projects that may require collaboration with other energy related industries.

The OPI conference was once considered a time for social gathering for those working in the Ontario oil and gas industry but it grew very quickly into a technical conference where industry professionals talked about their projects and used the venue to network with other industry professionals.

Our OPI conference was recently directed towards becoming a trade show and prospect exposition but the general lack of activity in our industry proved to be unsupportive of this concept. Today, we look to collaborate with other energy sectors in order to bring a broader set of minds together that may create new energy-related developments that in turn reinvigorates our own oil and gas industry through integration of energy concepts and collaboration of a diverse group of professionals. It is in this new direction that we find hope that professionals from other energy sectors see the potential of collaboration on integrated energy projects with our oil and gas industry that will carry all of us forward into a cleaner and brighter energy future.

Ian M. Colquhoun, Conference Chair

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Speaker Biographies and Abstracts

Block 1 – Energy Storage

Jug Manocha, Operations Engineer, Ministry of Natural Resources and Forestry

Jug Manocha is an operations Engineer with the Petroleum Operations Section of the Ministry of Natural Resources and Forestry in London.

He has thirty years of experience in both the industrial and the regulatory sectors. He is the founding and member of the technical committee of the CSA Z341 Storage of Hydrocarbons in Underground Formations and of the Sarnia Cavern Operators Group. He has been involved in design and operations, maintenance programs, cavern development, integrity testing, incident investigations, regulations and standards development.

Jug ran a storage symposium in Fall 2017 though the OPI. He has presented about Storage in Ontario and several other topics at the OPI conference.

Jug defines "Generating Collaborative Energy" as way of working with the industry and regulators to create safe and reliable energy projects that provide provincial benefits.

Jug has been successful in developing the standards for underground storage and in developing integrity testing and maintenance programs for ongoing use of a natural resource.

Jug has received the Ontario Amethyst Award for work done for plugging a hazardous flowing well. Jug has been dedicated to sharing his knowledge with the Petroleum Industry and in 2017 he received the Award of Merit from the OPI.

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Jug Manocha - Abstract

Hydrocarbon Storage in Porous Rock Reservoirs and Salt Solution Mined Caverns in Ontario

The underground storage of natural gas and liquefied petroleum products in geological formations is a provincially significant industry with economic, environmental, and safety benefits for the companies and residents of Ontario. There are 35 active natural gas storage pools in Ontario, with a total working storage capacity of approximately 7.5 billion m^3 (265 Bcf). Most of these pools utilize former natural gas-producing Guelph Formation pinnacle reef reservoirs. In addition, there are 70 petrochemical storage caverns in salt, with a combined storage capacity of 3.5 million m^3 (22 million barrels). These caverns are solution mined within the Salina A-2 Unit and B Unit.

In Ontario, hydrocarbon storage in porous rock reservoirs and salt solution mined caverns is regulated under the Oil, Gas and Salt Resources Act where it adopts the national standard for these facilities. The Canadian Standards Association Standard Z341 - Storage of Hydrocarbons in Underground Formations dictates requirements for underground hydrocarbon storage. This standard incorporates life cycle considerations and requires inherent safety features to be built into the well design, construction, operations and maintenance to ensure long term mechanical integrity of the storage systems. It is important to note that the reservoirs used for natural gas storage are provincially significant and that the designation of storage areas occurs under the authority of the Ontario Energy Board.

The steadily increasing demand for natural gas in Ontario has created a continuing need for additional storage capacity. There are a few remaining depleted or nearly depleted natural gas reservoirs with potential for use as storage pools, but most of the larger gas-producing pinnacle reefs in Ontario have already been converted to storage. The potential value of storage rights is an additional incentive for industry to explore for undiscovered reefs. There has also been a significant gain in the volume of available storage through delta pressuring of the reefs currently in use.

Potential exists for incorporating additional depleted reservoirs to increase overall storage capacity. One recent trend has been an increase in the number of reservoirs utilising delta pressuring, where they demonstrate suitable integrity. There is also potential to develop smaller reservoirs. There has been some further conversion of former solution mined caverns in the Sarnia area into hydrocarbon storage service, and a project has been recently approved to store compressed air as energy storage in a former salt solution mined cavern near Goderich. It is expected that the trends toward increasing storage capacity in both porous rock reservoirs and salt caverns will continue.

Michael Learn, Drilling and Reservoir Engineer, Union Gas Limited

Mr. Learn is a Principle Drilling and Reservoir Engineer at Union Gas Limited in the Underground Storage department with eleven years of experience in the gas storage industry. He obtained a Bachelor of Engineering Science and a Bachelor of Arts in Economics from the University of Western Ontario in 1994 and 1995 respectively. From 1997 to 2007, he worked for Windsor Salt as a project engineer and brine field supervisor. Michael has been on the CSA Z341.1 Technical Committee for six years and is currently the Vice Chair for the Reservoir section.

NOTES

Michael Learn - Abstract

Natural Gas Storage – The Dawn Hub

Union Gas operates the largest underground storage facility in Canada, and one of the largest in North America, at our Dawn Hub, southeast of Sarnia. The underground facility comprises of both transmission and storage capability for southwestern Ontario.

There are ten major pipelines interconnected at Dawn, providing customers with access to multiple supply basins and key consumption markets. These gas lines are a vital component for a reliable, steady supply of natural gas.

The natural gas storage that is closely connected to Dawn is operated by Union Gas or Enbridge's Tecumseh facility. Union Gas has twenty three underground natural gas storage reservoirs that hold enough natural gas to heat 2.4 million households all winter long. The Tecumseh storage facility is also located in connected to the Dawn. Together, there is over 260 BCF of gas storage connected to Dawn. Natural gas reservoirs provide a necessary service for customers. The reservoirs balance the natural gas distribution system by augmenting pipeline supply to meet daily, weekly or annual requirements. They supply gas due to winter heating, gas supply disruptions or summer co-gen requirements and also take gas during low requirement periods. They are a shock absorber for the gas flow through pipelines connected to Dawn.

The transmission and storage facilities associated with Dawn together provide access to affordable, reliable and secure natural gas.

Eric Tharumalingam, Graduate Researcher, University of Waterloo

Eric Tharumalingam is a graduate researcher who works with Dr. Maurice Dusseault to further develop Compressed Air Energy Storage (CAES) in an Ontario context. The research goals that Eric is pursuing involve a complete first order design framework for CAES; the framework will cover a range of energy demands, geological conditions, and turbine parameters. He is also developing a finite element model of thinly bedded salt caverns focusing on cavern communication as well as creep deformation. In the late stage of his Master's degree he hopes to incorporate monitoring to better calibrate these computer models.

Eric believes that energy storage is a vital and often overlooked component of Ontario's energy future.

Eric defines "Generating Collaborative Energy" as an opportunity to synthesize existing niches of knowledge and technology in energy.

Eric holds a bachelor's degree in Geological Engineering from the University of Waterloo. He has completed six student placements at esteemed construction and energy conservation companies.

NOTES

Eric Tharumalingam – Abstract

Compressed Air Energy Storage (CAES)

According to National Resources Canada, renewable energy accounts for 18% of Canada's total primary energy supply. Ontario currently has the highest capacity of wind power and is home to the largest solar farms in Canada. Renewable power sources require "balancing" to provide reliable and affordable energy. This calls for grid-scale energy storage to avoid frequent curtailment of wind and solar power. Compressed Air Energy Storage (CAES) proves to be a viable storage option because it is low cost, low-impact, low risk, and mature technology. Research findings include a design framework that incorporates: renewable energy potential, energy demand, proximity to infrastructure, mechanical equipment, geomechanics, and a sizing schematic. Renewable energy potential was characterized by existing wind or solar farms in the area, as well as prospective wind/solar energy facilities in a given area. Energy demand is generally determined by proximity to cities, and infrastructure is based on existing natural gas and transmission lines. To develop a first order design for a storage cavern, mechanical equipment must be selected to adequately meet the energy demand required. From here, one may determine the site geology, more specifically the depth and thickness of the salt formation. This information is then used to determine whether multiple caverns are required, and offers some sense of the shape (i.e. long horizontal galleries, short caverns etc.). Finally, a volume for each cavern can be determined based on the shape, energy demand, and mechanical equipment required. With the design framework, one may develop a first order design for a compressed air facility in Ontario. The results described will pertain to specifically Sarnia, Goderich and London. These regions are selected to apply the design framework based on earlier research by the team, wherein it was determined that these are areas where CAES will prove beneficial. However specific the results are, the design framework will prove beneficial for grid scale projects with some opportunity to scale down to an industrial setting.

David R. Thompson, President, Northern Cross Energy Limited

David Thompson is President of Northern Cross Energy Limited, an integrated natural gas production company in Ontario, which he founded in 1984. He is also a founder and Chairman of Next Hydrogen Corporation, headquartered in Ontario, which has developed and markets grid scale electrolysers for the production of green hydrogen from surplus of peak power.

He is a mechanical engineer from Queen's University with more than 35 years of experience in the energy industry in Canada and internationally.

In addition to his background in oil and gas exploration and production, David has broad experience in clean and renewable power projects, including gas fired generation, wind and solar power. Among other executive positions he was a founder and CEO of Port Albert Wind Farms and Smart Pipeline Services.

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David Thompson - Abstract

Underground Energy Storage in Porous Reservoirs in Ontario

The large-scale development of renewable energy in Canada and around the World has created periodic surpluses of electricity due to the intermittent nature of wind and solar energy production. This has given rise to the need for large scale energy storage for periods of minutes, days and months.

While there are other options such as batteries for short term storage, underground storage presents opportunities for storage of large amounts of energy for longer periods of time. Southern Ontario has an extensive electric power and natural gas distribution grid. It is also blessed with an abundance of high quality natural gas reservoirs, most of which have been converted to natural gas storage once they have been depleted. Some reservoirs, which are not close to major natural gas transmission lines are substantially depleted, but not currently developed for storage.

This presentation will focus on options for using existing and perhaps new porous underground storage reservoirs for longer term energy storage. Options include, compressed air energy storage, hydrogen storage and a combination of hydrogen and natural gas (power to gas).

Block 2 – Environment and Risk Management

Shawn Williams, Environmental Analyst, Indian Oil and Gas Canada

Shawn Williams is an environmental professional with fifteen years of oil and gas experience ranging from fieldwork, project management, compliance and management system implementation, and sustainability initiatives. Shawn has experienced the industry from the service and producer side and most recently, with the Indian Oil and Gas Canada, which regulates oil and gas activity on First Nation land.

Shawn defines "Generating Collaborative Energy" as ability to move beyond the silos of our professional practice or organizations to address the significant non-technical issues facing the energy sector.

Shawn has an interest in expanding the practice of incorporating environmental sustainability, ecological resilience and payments for ecosystem services into business strategy.

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Shawn Williams – Abstract

History, mandate and operations of the Indian Oil and Gas Canada organization

The presentation will describe the history, mandate and operations of the Indian Oil and Gas Canada organization with comments on our environmental remediation, reclamation and surrender process. Two case studies will be given to demonstrate the complexities of balancing regulatory requirements, rights-holder values and corporate interest at the retirement phase of oil and gas development. The presentation will end by discussing how some of the themes of Aboriginal reconciliation are applied to the management of oil and gas development and retirement

Gary Winthrop, Senior Remediation Specialist, Matrix Solutions Inc.

Gary Winthrop is a Senior Remediation Specialist who works with upstream, midstream and downstream oil and gas producers to help them implement pragmatic remediation solutions to their contamination issues. Gary has a Civil Engineering Technology diploma from the Northern Alberta Institute of Technology and is a Team Lead within the Assessment, Remediation, Reclamation and Monitoring practice at Matrix Solutions Inc.'s Calgary office. Gary is a professional technologist with over 23 years of environmental consulting experience predominantly across Western Canada.

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Gary Winthrop – Abstract

"Omaha!" A Pundits Playbook to In-Situ Remediation of PHCs

Gary Winthrop, P.Tech.(Eng.) – Senior Remediation Specialist

Matrix Solutions Inc., Calgary, Alberta

"Omaha is a run play, but it could be a pass play or a play-action pass, depending on a couple things: the wind, which way we're going, the quarter, and the jerseys that we're wearing. It varies, really play to play. So, there's your answer to that one." – Peyton Manning

Selecting a winning strategy for in-situ remediation of Petroleum Hydrocarbon (PHC) impacts is similar to calling plays in football. There are many factors that should be considered in the decision making process such as field position (concentrations relative to regulatory criteria), strength of the defence (geology – permeability), and time on the clock (desired or required closure date), to name a few. Unless you are certain to execute a hail mary, in-situ remediation usually requires the combination of two or more technologies to reach the end zone to accomplish remediation closure. Whether you are new to the remediation game, or a seasoned practitioner, a pundits look at in-situ remediation through a football analogy will offer EPEX 2018 delegates a fresh and fun view of the technologies available and relevant in Canada.

Through project experiences, literature reviews, and participation at remediation focused industry forums, Matrix remediation specialists have developed a playbook of remediation options to help clients make informed decisions on which technologies are best-suited for their remediation challenges. The playbook helps Matrix remediation practitioners systematically and efficiently navigate through the many options available and more closely examine those likely to provide a successful outcome. Many of the remediation options available in the playbook and relevant to the Canadian environment are identified in this presentation.

To illustrate the options, the presenter will lead the audience through a typical football drive to the end zone in which he describes the technologies available for defending PHC plume migration (barriers and interceptors), and the technologies available to attack free-phase, adsorbed phase and dissolved phase PHCs in a first, second and third down scenario, respectively. This trip down the field will take you into the end zone for remediation closure.

Block 3 – Hydrocarbons

Laurent de Verteuil, Mundo Nuevo Limited

Dr. Laurent de Verteuil is a Petroleum Geologist and Basin Analyst with over 25 years of post-graduate experience. Most of this time has been spent in Trinidad and Southeast Asia, working for BP, BG, and smaller independents. His experience covers the full asset life cycle including new ventures, exploration, development, reservoir modelling, geosteering, and subsurface management. Laurent has worked in and led multidisciplinary teams, evaluating basins and plays, acquiring and exploring acreage, planning field developments, delivering reservoir models, drilling appraisal and development wells, and managing reservoirs and wellstock. He has worked basin and field scale projects from over 20 countries globally. He is a keen field geologist and experienced consultant and small business and project manager. Laurent moved to London last year from Malaysia, with his wife Jean and their daughter Leila. He founded the firm Mundo Nuevo Limited here to pursue consulting opportunities in oil and gas. Laurent holds a doctorate degree in geology from the University of Toronto.

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Laurent de Verteuil – Abstract

The Ontario Opportunity – A Basin-Entry Perspective

Oil production in Ontario has declined in recent years to less than 360,000 barrels per year. Gas production, at ca. 5.5 bcf per year (~938,000 boe), is similarly down from 1990's highs of about 14 bcf. This situation is coupled with minimal new exploration as measured by drilling activity. Reversal of the production decline will only be achieved through new and successful investment in exploration by existing players or new entrants to the basin. This paper examines components of the basin-entry decision and elements of some best practice workflows widely used to assess risk and economic potential in proposed new ventures. The opportunity is framed using the example of an Ontario onshore oil greenfield new venture.

New entrants to existing basins and plays primarily seek opportunities to "organically" grow hydrocarbon reserves (=corporate value) through successful exploration drilling. To be internally competitive for funding, all such opportunities must fully align with the corporate growth strategy. This means that they must first be scale-appropriate for the organization's capital resources – neither too big nor too small – and secondly, they must comprise a balance of Risk vs. Reward that suits organizational appetite for both. Ontario oil pools are small, typically producing < 2 million barrels over 10 – 15 years. Fiscal terms, however, are attractive, and subsurface exploration risk is moderate. This limited scale, however, restricts participation in the Ontario patch to small players – those having new venture budgets less than US$10 million.

Once the scale of the opportunity is a fit, prospective basin entrants consider the barriers to economic basin entry, focusing particularly on those risks over which they exert least control. Such potential deal-breakers may be grouped into five categories: (1) Sociopolitical – regulatory framework, taxation, judicial, and geopolitical. (2) Commercial – access to markets and monetisation. (3) Organizational – access to technology and labour. (4) Surface – access to acreage. (5) Subsurface – the petroleum systems elements and maturity of plays. While each area has its issues, within the over-arching constraint of opportunity scale, the main barrier to entry, or choke, is within the Subsurface. Strategies for cost-effectively mitigating inherent subsurface risk are available and hold the key to reviving production in Ontario.

While not new, Play Based Exploration workflows (PBE) are a systematic integrated application of tectonostratigraphic and petroleum systems principles, with play fairway analyses, for risked prospectivity evaluation. Application of such techniques is the best way to de-risk the subsurface choke and so find new oil in an old basin. The excellent well-file, e-log, cuttings/core, and production databases of the OGSR Library are critical resources for enabling further exploitation of these marginal plays. All effective modern deployment of exploration capital, however, is seismic-driven. The general lack of accessible seismic for regional prospectivity evaluation represents a serious obstacle for the Ontario upstream industry. A mechanism is needed to make some of these play-building data available to explorationists seeking to identify and promote new hydrocarbon opportunities in Ontario.

Fred Longstaffe, Laboratory for Stable Isotope Science, The University of Western Ontario

Fred J. Longstaffe is a Professor of Geology at The University of Western Ontario who works with stable isotopes of carbon, hydrogen, nitrogen and oxygen to trace subsurface fluid sources and movement in the earth's crust – when he is not using the same tools to trace climate change since the last Ice Age, as inferred from lake sediments, or the life and times of the woolly mammoth, mastodon, giant beaver and ancient humans, as recorded in their hair, teeth and bones. Fred believes that the stable isotope compositions of subsurface formation waters, oil and gas in southern Ontario provide unique signatures of their origin. Fred defines "Generating Collaborative Energy" to be our concerted effort to sustain both a healthy economy and environment. He looks forward to achieving a 'Triumph of the Commons'. Fred is the Canada Research Chair in Stable Isotope Science at Western, with appointments in Earth Sciences, Anthropology, Biology and Geography, and a member of the Royal Society of Canada. Fred holds a BSc in Geology from the University of Windsor and a PhD in Geology from McMaster University.

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Fred Longstaffe- Abstract

A Geochemical Approach for Tracing Leaking Well Fluids in Southwestern Ontario

F.J. Longstaffe[1], M.E. Skuce[2], T.R. Carter[3], J. Potter[2]

[1] Department of Earth Sciences, *The* University *of* Western Ontario, London, Ontario
[2] Formerly, Department of Earth Sciences, *The* University *of* Western Ontario
[3] Geological Consultant, London, Ontario

In 2011, the Ministry of Natural Resources and Forestry (MNRF) initiated a project in collaboration with *The* University *of* Western Ontario to acquire isotopic fingerprints of the water and natural gas in the Paleozoic bedrock of southern Ontario. The results can be used to identify the probable geological sources of formation waters and natural gases leaking from orphan wells in southwestern Ontario. This information can then be used in the design of the most cost-effective approach to plugging such wells. This tool is based on significant isotopic differences among formation waters from different strata within the Paleozoic section of southwestern Ontario and likewise for the gases from various natural reservoirs in the region. That such differences existed had been identified by several previous researchers over the last 30 years. Our work has built substantially on this foundation in three ways. First, this study has characterized the isotopic compositions ($\delta^{18}O_{H2O}$, $\delta^{2}H_{H2O}$, $\delta^{34}S_{SO4}$, $\delta^{18}O_{SO4}$, $\delta^{13}C_{DIC}$, $^{87}Sr/^{86}Sr$, $\delta^{37}Cl$ and $\delta^{81}Br$) of groundwater in the region, which show distinctive differences among bedrock formations, allowing determination of unique 'fingerprints' for each formation. Second, the work has added a substantial number of isotopic analyses ($\delta^{13}C_{CH4}$, $\delta^{13}C_{C2H6}$, $\delta^{13}C_{C3H8}$, $\delta^{13}C_{CO2}$, $\delta^{2}H_{CH4}$, $\delta^{2}H_{C2H6}$) from a new, extensive suite of natural gas samples from the major Cambrian through Silurian natural gas reservoirs in the region. The isotopic compositions of these gases, along with highlights of their most distinguishing features, provide 'fingerprints' that, combined with geological knowledge of the region, should help geoscientists make the best possible interpretations regarding the sources of leaking gases at orphan wells. Third, a Bayesian mixing model has been applied to the formation water data to develop a tool for identifying the source(s) of leaking fluids. This model determines the possible range of proportions for each source and the probability distribution therein. The results of the project are on file with the MNRF and the methodology for the mixing model has also been published (Skuce et al., 2015).

Skuce, M., Longstaffe, F.J., Carter, T.R., and Potter, J. (2015) Isotopic fingerprinting of groundwaters in southwestern Ontario: Applications to abandoned well remediation. Applied Geochemistry 58: 1-13.

Brian Main, VP Business Development, Gedex Systems Inc.

Brian started his career with Schlumberger testing oil wells off the coast of West Africa, mainly Angola, Zaire, Congo, and Nigeria.

He is part of the founding team of Gedex, a company created to develop and deploy new transformational, low noise, high resolution airborne gravity gradiometry to mineral, oil and gas, space, and other applications. He currently serves Gedex in the role of VP Business Development and New Ventures.

Brian obtained his BSc. in Mechanical engineering at the University of Waterloo, his Masters of Business Administration at the University of Western Ontario, and he is a graduate of the Directors program at the University of Toronto.

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Brian Main – Abstract

Gedex High Definition Airborne Gravity Gradiometer - Potential for SW Ontario

The Gedex High-Definition Airborne Gravity Gradiometer was designed and developed to deliver measurements of the gravitational field with an improved signal-to-noise and resolution. Modeling and practical experience have shown the value of this improved data quality for discovering resources and mapping geologic features. The Gedex HD-AGG™ was designed to achieve a resolution of 1 Eotvos $Hz^{-1/2}$ or 1 Eotvos RMS noise at a spatial resolution of 60 m when flown from a fixed wing survey aircraft.

The system consists of proprietary sensors, a flight cryostat, and an isolation system together with proprietary and non-proprietary software. System components were described, and the performance of the individual elements shown, by Carroll, Hatch and Main (2010). Current system performance was addressed by Annecchione, Hatch, Hefford and Wong (2018).

Given the increased signal to noise resolution, the system is expected to have a transformational impact on mapping the Earths subsurface by density for mineral and oil and gas exploration. In particular, it will see smaller bodies of economic interest and see deeper with greater clarity. Gedex is only the second company in history to bring commercial gravity gradiometer technology to market (all other systems being developed by Lockheed Martin). Currently flown in a Cessna Caravan the system represents world leading capabilities and Gedex anticipates improving this performance by over a factor of two in 2018 when it commences surveys using a Dash-8 platform. This paper will review the system, some test results to date, and explore its potential for exploring for petroleum in SW Ontario.

Workshops

Building a Regional 3-D Geologic Model of the Paleozoic Bedrock of Southern Ontario

Present by Terry Carter and Liz Sutherland

Terry R. Carter, MSc, P.Geo.

Terry retired as Chief Geologist, Petroleum Operations, of the Ontario Ministry of Natural Resources at the end of 2014 after 38 years working for the Ontario government, and is now a Consulting Geologist in London, Ontario. Terry specializes in mapping, modelling and interpretation of the Paleozoic bedrock geology of southern Ontario, its oil, gas and salt resources, and regional bedrock aquifers. He is a passionate supporter of the Ontario Oil, Gas and Salt Resources Library in London, and its role in managing and providing public access to data on the subsurface Paleozoic geology of southern Ontario, and the use of GIS technology in accessing and interpreting this data.

Terry is co-author of the book Subsurface Paleozoic Stratigraphy of Southern Ontario, published by the Ontario Geological Survey in 2010. Terry is currently coordinating a project to produce a 3D geological model of the Phanerozoic geology of southern Ontario.

Elizabeth Sutherland, BSc.

Liz is a GIS professional who works with the OGSR Library to curate, analyze and interpret Ontario geology data collected through the Oil, Gas and Salt Resources Act. Liz is the founding leader of the London GIS Working Group, coordinator of an annual GIS Open House and creator of a public-facing animation entitled "Communicating 3D geological models to a broader audience: a case study from southern Ontario." Liz holds a BSc in Geographic Information Sciences from Western University.

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Building a Regional 3-D Geologic Model of the Paleozoic Bedrock of Southern Ontario

T.R. Carter[1], F.R. Brunton[2], J. Clark[4], L. Fortner[5], C. Logan[3], H.A.J. Russell[3], M. Somers[4], L. Sutherland[4], K. Yeung[2]

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[2] Ontario Geological Survey, Ministry of Northern Development & Mines, Sudbury, Ontario
[3] Geological Survey of Canada, Natural Resources Canada, Ottawa, Ontario
[4] Oil, Gas, & Salt Resources Library, London, Ontario
[5] Petroleum Operations Section, Ministry of Natural Resources & Forestry, London, Ontario

A regional 3-D geological model of the Paleozoic bedrock of southern Ontario is under development, for completion in late 2018. The model encompasses the entire Phanerozoic succession of southern Ontario (110,000 km^2), comprised of up to 1,400 metres of sedimentary strata straddling regional arches/forebulge zones separating the Appalachian Foreland Basin from the Laurentian craton and Michigan Structural Basin. This ambitious initiative provides an unprecedented regional 3-D perspective and digital framework to support investigations and decision-making related to resource exploration, hydrogeological/environmental investigation, education, resource management and land-use planning. It is amenable to numeric modelling and provides regional context for site-specific investigations.

Model construction is guided by an updated regional lithostratigraphic chart, and utilizes Leapfrog® Hydro - an implicit modelling application. Layers representing 58 formations are constructed using top-bottom formation depths from 20,221 borehole records in Ontario's public petroleum well database (www.ogsrlibrary.com), supplemented by Ontario Geological Survey (OGS) deep boreholes. An OGS digital bedrock topography surface is combined with revised subcrop geology to assemble a grid of 3-D points that approximate the subcrop surface of each formation, and together with digitized 3-D surface polyline and point constraints, are used to better align the modelled layers. The modern topographic surface is integrated using SRTM DEM data, NOAA lake bathymetry and Canadian Hydrographic data for smaller lakes. Manual editing has been critical to resolving inaccurate thickness extrapolations, gaps in layers, missing/inaccurate formation depth data, obsolete/inconsistent stratigraphic assignments, anomalous outliers, and layer truncation issues at the cuesta/escarpment margins.

Model development is an iterative cycle of interim modelling, expert geological appraisal, and editing of geological data using geophysical logs, drill cuttings/core resulting in a revised dataset and improvements to the petroleum well database. Data integrity and model construction have improved such that the current model (version 6) provides a geologically robust representation of regional bedrock geology.

Core Display

Presented by Maia Somers

Maia Somers has been with the OGSR Library since 2016, most recently as the Geology and Laboratory Technician. Maia uses geologic data and GIS to research the Paleozoic geology of Southern Ontario. Her work in producing an updated version of the Subcrop Boundaries and contribution to ongoing quality assurance efforts has greatly benefitted the project: "3D Geological and Hydrogeological Modeling of the Paleozoic Bedrock of Southern Ontario."

Maia completed an Honours BSc in Geology and Physical Geography at Western University and has a strong knowledge and passion for blending the two disciplines together in the study of the earth. Maia is an avid outdoor enthusiast and is always searching for new areas to explore and indulge in her love of soil, rocks, and rivers.

NOTES

Select Cores of Ontario

The following cores will be made available during the workshop segment for hands-on interactivity and discussion following a description from presenter Maia Somers:

Well Licence	Location (COUNTY-Township-Lot-Concession)	Well Name	Core Number	Rock Formation	Significance
T011552	ESSEX-Sandwich West	MTO X11-5	1118	Dundee	Hydrocarbons
T006078	ELGIN-Yarmouth 9-1	OGS 82-3	861	Amherstburg	Environment and Risk Management - Regional aquifer, salty or sulphurous, can exhibit artesian flow
T007529	LAMBTON-Enniskillen-18-1	Imperial 831 (GBS-26)	595	Dundee	Hydrocarbons – Ontario's First Oil Pool
T003563	HURON-Goderich-2-MC	Domtar Goderich S.T.#1	1072	Salina	Energy Storage – Potential for Compressed Air Energy Storage in Caverns
T005813	KENT-Tilbury East-4-IX	Consumers 33409	751	Guelph	Energy Storage/Environment and Risk Management – Natural Gas Storage in Lambton County, Important Regional Aquifer Shallower
T006056	Bruce-Albemarle-25-W	OGS 82-4	1103	Ordovician, Precambrian	Understanding deep rocks

The OGSR Library has initiated a catalogue of high-resolution core photographs to help our clients conduct their research remotely and more efficiently. Each core is photographed dry, wet, and under ultraviolet light. Over 13,000 photographs have been taken of approximately 4,350 core boxes.

A small number of photographs for the above cores have been printed in the back of this program.

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Ministry of Natural Resources and Forestry, Petroleum Operations Section

Location:

MNRF – Petroleum Operations Section

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The Petroleum Operations Section with the Ministry of Natural Resources and Forestry in Ontario is regulator for wells used for oil and natural gas production, salt solution mining, underground storage, oil-field fluid disposal, geological evaluation and compressed air energy storage. For more information visit www.ontario.ca/petroleum

Ontario

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Stream-Flo sincerely thanks the gas storage industry and also the OPI for allowing us to be part of such a dynamic effort.

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The Wellmaster team is looking forward to seeing our long-term clients at EPEX 2018 and showing new clients our commitment to "Make a Difference" in their operations.

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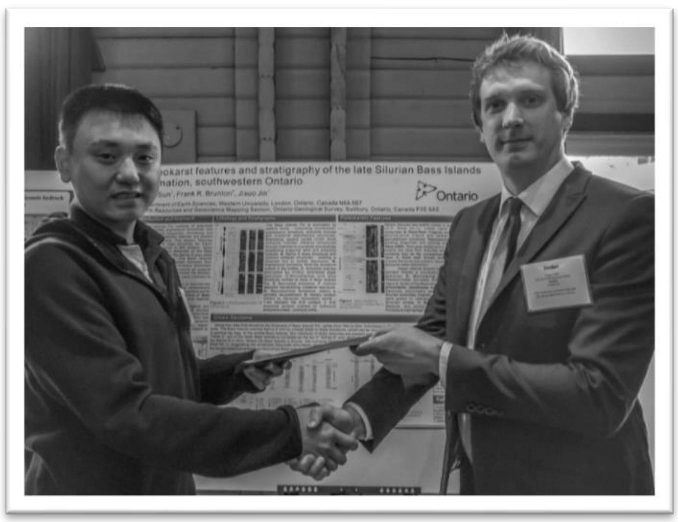
Student Poster Competition

University and college students were invited to submit posters on themes of Ontario Energy or Geology.

Posters are available for viewing outside of the main speaking area, behind the registration desk. Judging for the competition will take place during the first coffee break at 9:15AM. All conference participants are encouraged to read the posters and welcome the students.

An OGSR Trust Scholarship will be awarded to the author of the top poster and two OGSR Trust Awards of Merit will be awarded to the top runner-up entries.

Congratulations to our 2017 winners:



Shuo Sun (left) receives his OGSR Trust Scholarship from OGSR Library manager Jordan Clark (right)

OGSR Trust Scholarship:

Shuo Sun: Paleokarst Features and Stratigraphy of the Late Silurian Bass Islands Formation, Southwestern Ontario

OGSR Trust Award of Merit:

Jai Duhan: Brine Disposal in Southwestern Ontario: A Siting Study to Support CAES Salt Caverns

OGSR Trust Award of Merit:

Paulina Marczak: Fracking Suitability Analysis of Kettle Point, Hamilton Group, and Marcellus Shale Formations: Southwestern Ontario Case Study

Ontario Petroleum Institute – Technical Volume Excerpts

Now in its 56th year an extraordinary amount of valuable technical information has been presented at OPI conferences. A selection of material relevant to the themes of this year's special conference have been reprinted here for your review, please enjoy.

All volumes can be found online:

http://www.ogsrlibrary.com/catalogue

Archived Technical Papers for Block 1: Energy Storage

Featured Article: Dyer, W.B. (1962). Underground Gas Storage in Ontario. *Ontario Petroleum Institute Gold Volumes, 1*(4).

Additional References

Carter, T. (2009). Bedded salt in Ontario: geology, solution mining, and cavern storage. *Ontario Petroleum Institute Gold Volumes, 48*(15).

Manocha, J. (2006). Natural Gas Storage Reservoirs & Salt Caverns Storage – Ontario Update. *Ontario Petroleum Institute Gold Volumes, 45*(8).

Martinson, E.V. (1969). Development and Operation of Northern Natural's Aquifer Gas Storage Reservoirs. *Ontario Petroleum Institute Gold Volumes, 8*(4).

Thompson, D. (1987). Bulk Transportation of Compressed Natural Gas in Ontario. *Ontario Petroleum Institute Gold Volumes, 26*(4).

Wolnik, J. (2007). Gas Storage – The Past, Present and Future. *Ontario Petroleum Institute Gold Volumes, 46*(11).

An address given before the
Ontario Petroleum Institute,
London, Ontario,
November, 1962.

UNDERGROUND GAS STORAGE IN ONTARIO

By

William B. Dyer

Union Gas Company Limited

Superintendent of Gas Dispatching

INTRODUCTION

THE rapid growth in recent years in the practice of storing gas underground is of remarkable proportions, and of prime importance and interest to all of us in the natural gas industry. It is hoped that a general review of the economic significance of storage, and of the various factors which characterize a good storage project, will be of interest to any who may take part in such an operation, or benefit from its use.

THE discussion is not confined to Ontario, nor to one particular type of storage pool, although specific reference will frequently be made to the facilities and experience of Union Gas Company of Canada, Limited, and its subsidiary, Ontario Natural Gas Storage and Pipelines Limited.

History

THE expansion of the whole natural gas industry in Ontario, as in the rest of North America, over the past 17 years represents one of the most remarkable industrial growths in our history, and it has been made possible to a large extent by underground storage. The problems which have had to be met are formidable. The effect of growing market demands, increasing proportion of gas use for space heating, and declining local gas supplies have made careful planning, economical and knowledgable operation necessary in order to serve the customer well and at a favourable price.

DURING the period of wartime shortage of construction materials and decreasing supplies of gas, it was necessary for Union and others to curtail the use of gas for space-heating purposes, and to help meet peak-loads with propane-air plants and manufactured gas.

WHILE Union continues its policy of purchasing all gas available from local sources within economic distance of its pipelines, and discoveries of gas in Southwestern Ontario have been quite significant, yet as the demand for gas mushroomed in the first decade after the war, the impact was profound. It was evident that additional supplies must be made available, and if we were to avoid unfavourable economics, ways must be found to level the annual load curve. There are basically two ways to balance the uneven seasonal sendout: to find additional warm-weather uses for gas and to meet high winter demands by supplementing current gas supplies with standby peak-shaving plants or storage. A combination of both methods, given adequate supply, would have several advantages: larger annual sales, effective peak-shaving, and maintenance of a high load factor on transmission facilities.

SO far as supply was concerned, it became apparent that if the post-war needs of Ontario were to be met, gas must be imported from outside the province. An agreement was signed in 1944 with Panhandle Eastern Pipe Line Company in the United States for the purchase by Union over a period of 20 years from date of first delivery of annual volumes of 5.5 billion cubic feet of gas, all of which is delivered in the months of April to October inclusive in each year. The first large deliveries under this contract began in 1949. A second agreement with Panhandle was signed in 1954 for interim supplies pending the completion of the Trans-Canada Pipeline. These additional volumes were received from November 1956 until October 1959.

UNION received its first gas from Western Canada in 1959 under a contract with Trans-Canada Pipelines Limited signed in 1955. This contract, extending for a minimum period of 20 years from date of first delivery, provides for steadily increasing volumes to be received by Union, levelling off in the 1969-70 contract year, at maximum annual deliveries of 64 billion cubic feet, on a 75% "take-or-pay for" basis. Two-thirds of the gas purchased each year from Trans-Canada is delivered in the seven months April to October, with only one-third in the five cold winter months. The unit price paid by Union for Panhandle and Trans-Canada gas reflects the fact that deliveries of such gas to Union are made largely in the summer season when heating demand is lowest, thus assisting the long-distance pipeline companies in maintaining higher load factors on their systems.

IT was underground storage of gas, of course, which enabled Union to buy in the summer months, large volumes of gas which otherwise would not have been available to it. In addition it has brought these other benefits: For the transmission companies it has been possible to increase the annual throughput of their lines, thus reducing the operating cost per Mcf (thousand cubic feet); to make larger volumes available to its distributing customers; to buy its gas at maximum contract volumes and to provide market protection in the event of failure of its facilities, even though it does not itself own storage. It is probably fair to say that all customers using gas supplied by a long distance transmission pipeline benefit at some time, in one way or another, from the use of sotrage by any one of them. For the distributing company, whether it owns storage or utilizes on a service basis storage space of others made available to it, it has been possible to buy pipeline gas cheaper by being able to take delivery in off-peak months at the commodity rate, and to supplement pipeline supply in peak periods by withdrawals from storage, thus avoiding high demand charges. It is common practice now for distributing companies to buy gas on a 90% take-or-pay basis year-round although Union is not obligated to take more than 75% of the annual volumes available to it from Trans-Canada. This provision in the contract allows Union the flexibility it needs in order to purchase additional local gas as new reserves are developed. Underground storage has permitted distributors to supply 100% natural gas, and at the same time relieved them of the necessity of operating other stand-by peak shaving facilities at a very high unit cost. It has allowed them to conserve this natural resource for prime uses, to supply it in larger volumes, by supplementing pipeline supplies available in peak periods, and to assure their customers a more dependable service in the event of failure of the suppliers' pipelines. It has also permitted them, because of lower costs, to compete more effectively with suppliers of other types of energy fuels, such as electricity, coal and oil, whose earnings are not at present limited by government regulations as are those of the gas utilities. For the ultimate consumer the chief advantage, apart from greater dependability, is lower cost, since the savings of the distributor in buying gas at a lower price assist it in earning a reasonable rate of return on investment without having to increase rates for gas service.

THE earliest known storage project was undertaken in Welland County, Ontario, in 1915, and this was followed a year later with the Zoar Field just across the border near Buffalo, New York. With improvements, the Zoar field is still operating today, 42 years later. In the Welland County area, the Consumers' Gas Company, of Toronto, is presently attempting to develop a new small, modern, peak-shaving facility. The storage industry generally grew more slowly until the late "thirties". Then, with dwindling local supplies in the populous areas of the continent, and rapidly increasing use for space-heating as well as for other new domestic purposes and more widespread industrial and commercial applications, more and more storage projects came into being. In the United States, as of December 31, 1961,[1] there were 54 companies operating 229 storage pools in 21 states, and with 9,617 wells and 166 compressor stations. These pools have a combined working storage capacity of 1.6 trillion cubic feet, and a total capacity of 3.1 trillion cubic feet. Figure 1 graphically illustrates the growth in use of storage in the U. S. A. In Canada there are presently 9 operating storage pools, with working storage capacity of 70.5 billion cubic feet, and total capacity of 106.7 billion cubic feet.[a(2)] Six of these, with 74.7 billion cubic feet total capcity, are operated by Union Gas in Lambton County, Ontario. There are at least eight projects planned or underway in Ontario, and these, together with existing projects, would give Canada working storage capacity of over 130 billion cubic feet, and total reservoir capacity of over 200 billion cubic feet.

UNION began its first storage operation in October, 1942, with the Dawn 47-49 pool in Dawn township, where it stored in summer months excess supplies of refinery by-product still gas from Sarnia. The neighboring Dawn 59-85 pool followed in 1943. In 1957, Union purchased the Payne pool for storage from Imperial Oil Limited, in 1960 added the Waubuno pool, and in August, 1962, commenced injecting gas into its latest storage area, Dawn 156. In addition, there is a sixth, the Dawn No. 1 pool, into which gas was first injected in small quantities in 1954. This area is not important however in the overall picture, as it is small, and with present facilities is not capacity capable of delivering its gas to markets at a significant rate. Figure 2 is a map showing the location of Union's storage pools and major connected facilities.

Figure 3 shows the growth in use of gas storage by Union Gas Company.

CHARACTERISTICS OF EFFECTIVE STORAGE

OF all the many and varied aspects of underground storage, the physical nature of the pools themselves is the most fundamental, interesting, and economically important. Most of this presentation will therefore take the form of a general, fairly non-technical discussion of the properties which together determine the nature of each pool. It is hoped that this approach may prove to be the most helpful way to lead a broader understanding of the use of storage in the overall pattern of gas utility operation.

THE emphasis will be on the relative quality of those features of storage projects which, taken together, classify them as suitable, and to make them more or less useful, according to the particular circumstances and needs of the operator. Although not every depleted gas pool or other geological structure is suitable, still, a project that might be considered marginal or useless to one company might be exactly that required by another.

FURTHER, with the ever-increasing use of storage in gas utility operation, almost every other phase in the complex business is in some way dependent on, or limited by it. It would thus be difficult, if not impractical, to describe the physical nature of storage pools separately from economic and operating considerations. Therefore, something of such matters as relative performance, economic advantages(3), costs, drilling and completion methods, performance tests, pressure limits, etc., will be mentioned here along with, and as they relate to, the inherent physical characteristics.

THE ultimate aim of the operator, in any case, is to acquire the most suitable property available, and then to develop it in such a way as to make the most of the existing physical properties - or, where possible, to improve them - so that the completed project will best meet his own special economic and operating requirements.

Economics

IT is important to keep in mind the fact that the cost of storage,-exploration, acquisition, rentals. development and operation - are justified only to the extent that the project helps to meet the overall requirements and obligations of the gas utility using it. All of these costs are, or should be, directly related to the physical assets or liabilities inherent in each pool. Such problems, for example, as bottom-water, large area-capacity ratio, poor deliverability, need for gas treatment plants or for recompletion or abandonment of old wells, can materially increase the cost of the project, and reduce the economic advantage to the operator and his customers. Obviously, as much knowledge as possible of such factors should be obtained in advance, for the cost involved might easily be prohibitive. For a project to be economically feasibl,e it must be possible for the operator to recover all of his costs within a reasonable period of time and to earn a really fair return on his investment by means of a saving in the overall cost of operation, rather than through increased rates.

THE capital cost of a gas storage project then, can be expected to vary widely depending on such factors as those mentioned above. For comparison, such costs are usually related on a unit basis to the total capacity of the project, although as pointed out later, factors other than size are often of equal or greater importance.

WHILE the present discussion is confined to underground storage, it may be interesting to note that storage of gas above ground, in low pressure tanks, steel pipe or higher pressure spherical holders can cost anywhere from $150.00 to well over $200.00 per Mcf of capacity.(4)

IN comparison, underground storage costs, sometimes including such items as acquiring rights, drilling, pipelines and compression facilities, commonly range, at least for depleted gas fields, from a few cents to just over one dollar per Mcf of total capacity. So far as can be ascertained, Union's unit cost for underground storage are not materially out of line with average costs prevalent in the United States.

THE ultimate tests of good storage - the result of careful planning, wise investment and efficient, experienced operation - are first: that it will assist the company in making larger volumes available to its customers, serving them the quantity they want when they want it, in immediate response to their greatly varying needs, and with greater dependability. Second: it will help the company to operate at the lowest possible cost - thus assisting in the sale of its gas at prices which are attractive to the customer in a highly competitive market. Third: it will help the company meet its obligation to conserve a valuable depleting natural resource by making possible a greater proportionate use in high grade applications.

FROM a technical viewpoint, there is no perfect storage facility. Each pool or group of pools used for storage must, in the last analysis, be considered on the basis of its merits as an integral part of the whole production, transmission and distribution system. This is why practically all storage pools in use today are controlled by distribution utilities: it is they to whom the customer looks to provide an economical and reliable energy fuel. It is therefore logical that the utilities consider it their responsibility to plan for and provide a storage system, or pattern, that fits the widely fluctuating demands and peculiarities of the market.

New Techniques

WITH the advances that have been made in recent years in underground storage engineering, many problems in planning, developing and operating storage have been overcome, so that today gas is stored successfully in geological structures that at one time would have been considered very risky. Aquifer storage, where gas is stored as a "bubble" in water-saturated rock strata, has become commonplace. (5) Aquifers even without a structural closure, or "trap" have also been tested as potential storage pools. Gas is now being stored as well in such places as an abandoned coal mine near Denver,[6] and a washed-out salt cavern in St. Clair County, Michigan.

Union Storage Pools

FORTUNATELY, the depleted gas fields in which Union stores its gas, with one exception, combine many of the favourable features discussed below. The reader is here referred to figure 4 for more detailed and factual data. Five of our six pools are Silurian reef structures - which are masses of porous dolomitic rock like small buried hills. They are usually somewhat elliptical in shape, extend in area from 160 to 800 acres and lie at depths from 1570 to 2000 feet below ground level.

THE gas reservoirs, which are in the upper part of the reefs, range from 250 to 300 feet in thickness and are surrounded and overlain by adjacent layers of dense rock. Figure 5 is a contour map, drawn on the surface of the rock formation containing two of Union's reef pools, Dawn 47-49 and Dawn 59-85. Figure 6 is a cross-sectional view of Union's Dawn 59-85 pool, showing the geological names of the rock strata, and some of the wells drilled in the area.

AS reefs, or bioherms, these small mounds of rock are remanants of ancient sea life which existed in the large shallow oceans which covered the land in Silurian times - some 300 to 500 million years ago. They were slowly built up by colonies of small marine animals and plants, on the debris of past generations, in much the same way as coral reefs are growing today in the South Pacific and other parts of the world. With the passing of many millions of years, the reefs turned to rock, were buried under other sediments (some of which, fortunately, later providing to be quite impervious), and were eventually filled with gas which had been filtering through nearby rock and become trapped in the structures.

OUR Dawn No. 1 pool (the exception) is in contrast, an elongated structural trap for gas formed by the development of porosity in two thin layers along a fault. It lacks many of the better qualities shown by the reef pools and is presently inactive. However, Union Gas plans eventually to improve the old wells by modern stimulation methods, to drill new wells, and upgrade piping and other facilities, so that the pool can take a useful part in our overall storage program.

PHYSICAL PROPERTIES OF STORAGE POOLS

Location

THE location of a storage pool is a prime factor: for greatest economy, it should be as close as practicable to the markets to be served and to the transmission line or other major source of supply. Transmission costs and the time factor are both involved here: it costs money to build pipelines, and it takes time to move gas through them to meet varying loads. At one time it was felt that storage pools ought to be very close to the market for these two reasons. It is true that this would probably be most desirable, but of recent years, storage pools located several hundred miles from major markets are used very effectively. This is especially true when the same transmission lines used for carrying gas to storage in summer are used for carrying a major part of the winter load from storage, thus maintaining a high load factor and less costly operation. Such is the case with Union's storage pools. (Fig. 2).

MODERN methods of gas dispatching too, made possible in part by more dependable weather forecasts and better communication (radio and telemetering, as well as telephone), also permit more distant storage pools to be effective. With careful operation and planning, gas can be made available to markets at all times at suitable pressures and rates of flow in advance of requirements.

Effective Trap for Gas

ANOTHER basic requirement of a pool is that it be a tight container for the gas to be stored in it. A first-rate reservoir should be enclosed by dense, leak-proof rock, and all wells drilled into it must be properly completed to ensure adequate protection against leakage.

AGAIN, with improved methods and engineering, a completely tight caprock is becoming, in some cases, a less vital consideration than it once was. It is now sometimes economical to collect and reinject gas which leaks from a less than perfect reservoir, [7] and indeed, even to accept a small loss, depending on the relation between the cost of the gas lost and the value to the operator of the storage facility. The storage pools operated by Union are all believed to be completely tight. Much evidence has been acquired by various tests on our older pools over the years to substantiate this fact and to permit us to verify our gas inventroy. Periods of shut-in are required from time to time for example, during which frequent pressure observations are made, in order to determine a stable reservoir pressure and so confirm a regular pressure-volume relationship, as is shown in Fig. 7, for Union's Payne pool. Any significant change in reservoir capacity, or loss of gas, can be expected to show up in such a study, and must be accounted for. Incidentally, the rate of increase or decrease in pressure observed during such tests after shutting in an operating pool is useful information also. It permits us, among other things, to estimate certain physical characteristics of the reservoir as a whole,[8] and to determine qualitatively the conditions of the important part of the reservoir close to and at the surface of the well-bore. A series of such tests will indicate any progressive change in the condition of the well or the reservoir. [9] [10]

Size

THE size of a storage pool is another obvious consideration: it must be able to hold sufficient volumes of gas to m et the demands made upon it, and yet not be so great that large amounts of capital are tied up in unused capacity or excess cushion gas. The cushion is the volume of gas which is maintained in the reservoir year-round, as a sort of permanent stored energy. Figure 8 is a drawing prepared to illustrate graphically the meaning of many of the terms used in the underground storage business.

THE combined energy of gas pressure and compressor-engine horse-power determines, for a given pool, the rate at which it can deliver gas from its wells. The cushion pressure is the lowest pressure the pool can be allowed to reach and still be able together with available installed horsepower, to produce a gas at a rate and pressure sufficient to meet the critical late-season peak demands which could be made upon it. It is determined by comparing the cost of installing and operating the additional horsepower which would be needed to achieve this same ability at a lower cushion pressure, with the cost of the cushion gas of equivalent energy it would replace. The proportion of the ultimate capacity of a pool held for cushion can vary also according to the use to be made of the pool. Union's Dawn 59-85 pool, for example, is used mainly for meeting peak-loads, and is normally held for this reason at higher pressures than the others throughout the season. It is designed to be held at a minimum pressure of 500 psi to be ready for possible late-season peaks, and the volume contained at this pressure represents its cushion. A safety factor must be allowed for unusual weather conditions, so that the pressure is not usually reduced to cushion in a normal winter.

SINCE cushion gas forms an integral, permanent part of the storage facility, it is logically a part of the utility's rate base. Interest on the capital invested in cushion gas is a part of the storage cost and should be assessed against the turnover gas. Therefore it is preferable to have a large volume of working capacity over a relatively small cushion volume.

THE ratio of cushion gas to ultimate capacity in Union's six operating pools is about 38%, which compares with 47% in the 229 pools in operation in the United States at December 31, 1961.

FIGURE 3 shows the experience of Union Gas in acquiring storage space in advance of requirements, and Figure 9 the necessity for some excess of both gas and space (depending on the season) so as to give sufficient flexibility in meeting annual variations in gas supply and send out.

THERE are several physical factors which determine the size of a storage pool, or rather its capacity for holding gas. One of course is the amount of empty space provided by the pores of the rock. It is surprising to learn that many laymen still visualize a gas reservoir as an open cavern. Actually, except for a few very special cases, it is almost solid rock but for the small spaces or pores within the rock. These represent only a small percentage of the total reservoir volume. Figure 10 illustrates a piece of diamond-drill core from one of Union's storage reservoirs. This is an exceptionally porous specimen, and is away above that usually found in a gas field. The estimated average effective porosity in Union's five best pools varies from 9 to 12-1/2%.

THE amount of open space in a gas reservoir, then, depends both on the percentage of porosity and the total volume of reservoir rock. Some storage pools are relatively thin and extend over an area of many acres. Most of Union's pools, however, have a relatively large capacity enclosed within a small area because of the unusual thickness of the gas reservoirs.

IT is never possible to know exactly the location of every point in the outer boundary of a gas reservoir, regardless of the amount of drilling done in and around it. Usually, enough wells are drilled around gas fields during the exploration and development stage to enable the operator to interpret the boundary of the pool with considerable confidence. Sometimes however, additional "delimitation" wells are drilled, on conversion to storage for the sole purpose of gaining more information on the limits of the reservoir. Such knowledge is necessary to ensure that the acreage included in the storage area is sufficient to enclose any small unknown extensions of the pool which might otherwise be tapped by some other party outside the area. Every storage area has such a "buffer zone" of protective acreage surrounding the gas reservoir. The proportion varies according to the geological nature of the pool. In Union's reef pools where the boundaries have been determined with a comparatively high degree of accuracy, the gas reservoir area averages about 34% of the total storage area. These buffer zones are a necessary integral part of the storage area, for they are in a sense the "walls to the warehouse".

THE pressure at which gas can be stored in a pool also directly affects the capacity: the higher the maximum pressure, the more gas that can be stored in a given space. The depth of the reservoir below the surface determines the original pressure to be expected in a normal gas field. This is commonly found to be about 0.47 x the depth, in feet. However, according to this relationship (the normal "pressure gradient"), the original pressure in most of Union's pools is well above normal for the depth.

IT is considered quite safe in all cases to store at least up to the original pressure of a gas pool, as mother nature managed to contain it this way for perhaps several hundred million years. This is the limit presently observed by Union Gas. Many operators have proved however, that it is safe under certain conditions to exceed original pressures by large amounts - as much as 58% in certain Michigan fields. Limiting factors, apart from surface facilities, are the strength of the rock above the reservoir to contain pressure, the tightness of the caprock, and the possibility of leakage from the edge of the reservoir due to the lowering of the bottom of the gas zone below the level of the "spillpoint." This is the highest point in the base of the leak-proof "caprock" surrounding the bottom of the reservoir. Research is presently being carried out to find more exact ways of determining the strength of overlying rock. It is believed at present that most sedimentary rocks can safely contain pressures of up to one pound pressure for each foot of depth.

ONE advantage sometimes obtained by exceeding original pressures is the control of the movement of water contained in underlying aquifers which might otherwise permanently enter the gas reservoir and reduce its capacity. The term aquifer is usually confined to a rock layer containing water acted on by external dynamic forces which could cause it to move into any available lower-pressure space. Although water-bearing strata lie beneath most of Union's storage pools, the water in them, to the best of our knowledge, is not affected by such forces, for it has never measurably affected the size of our gas reservoirs.

A more important, and obvious advantage in storing at higher pressures is that the same size reservoir will contain more gas. - even more than expected from the proportional increase in pressure. This is because of the phenomenon of supercompressibility - a long word, which simply means that more gas can be squeezed into a given space for each pound increase of pressure at high pressures than at low pressures. There is an economy too in the cost of the additional horse-power required to pump gas at higher pressures, for more gas can be moved into storage for each pound increase in compression discharge pressure.

THE calculation of the gas volume contained by a reservoir, at its original or maximum pressure, or at any lower pressure, is of fundamental importance in a storage operation. Since it can become quite complicated, only brief mention of some of the principles will be made here.

THERE are basically two methods: The first, or volumetric method, is the only one which can be used before much production has taken place. The original gas volume is estimated from combining available information on total volume of the gas reservoir, the porosity, and the original pressure. Because knowledge of each of these is limited, the result is only approximate.

THE second, known variously as the material-balance, production-pressure decline, or Boyle's law method, is usually far more accurate, but requires that much of the original gas be produced, perhaps up to 25%, before it is completely reliable. In a stable, constant-size reservoir, where there is no large underlying oil section or active water-drive, it is possible from production records and pressure observations to determine the volume of gas produced for each pound drop in pressure. This figure can be applied to any reservoir pressure to find the content at that pressure. Many variables must be accounted for in the process: Measured volumes must be calculated at standard conditions by compensating for pressure, specific gravity, temperature, supercompressibility, etc. The pressures must be as nearly representative of average conditions as possible. Any other factors affecting the uniform relation between gas content and pressure, such as the presence of a water-drive, complicate the calculations greatly, but with sufficient information can usually be accounted for. Figure 7 illustrates, for Union's Payne pool, a very consistent relationship betwen pressure and volume over the years. From such a graph, a highly reliable calculation of "gas volume per pound pressure" can be determined. To compensate for supercompressibility and obtain a straight line relationship, the supercompressibility factor "Z" is here applied to the pressure.

Deliverability

EVEN though a depleted gas field, or other suitable reservoir for storage may be available which is leak-proof, of suitable capacity and strategically located, it must to be really effective, have the ability to deliver its contained gas at high rates in order to meet the extremely heavy demands placed on a utility on peak days and hours. The deliverability of a storage pool is determined primarily by the permeability of the gas reservoir rock. This is a measure of the degree of interconnection, or size and number of openings, between the rock pores. It determines the rate, or speed, at which gas can move through the rock for a given pressure differential. The better the permeability, the less will be the frictional resistance to the movement of gas through the reservoir. A smaller pressure difference between the pressure deep in the reservoir and the flowing pressure at the well-bore is required to give the same rate of flow in a more permeable reservoir. It is possible to have a rock with high porosity and low permeability. Such a rock would hold a lot of gas, but would deliver it slowly. The reverse can also be true. Union's storage pools have both high porosity and permeability, although in varying degrees, and this is the ideal combination. It is porosity and permeability together which determine the overall performance rating of a storage pool. The most critical part of the reservoir is at the surface of the well-bore, where the velocity of the moving gas is greatest. If the porosity or permeability should be poor here for any reason, the deliverability of a well can be greatly affected, no matter how good the formation is a little further away. Modern methods of well stimulation, such as acid treatment and various ways of fracturing the rock, can greatly improve the deliverability of wells in poor condition or in low-permability reservoirs.(11) (12) (13).

SEVERAL other factors help to detrmine the rate at which a storage pool can deliver, or receive, its gas. Outside the field area itself there are such considerations as compressor capacity, line size, etc. But at the pool, in addition to the rock properties which make high deliverability possible, the number and quality of the wells drilled into the formation are next in important.

Much has been written on methods of drilling and completion, so the remarks here will be confined to some of the things Union has learned in developing reef pools. In the early days in the area, all drilling was done by cable tools. However, when the drill reached the top of a gas pool of this kind, it was not possible to penetrate it safely more than a few feet, and still be able to control the pressure and flow. In some cases the nature of the reservoir was such that a well would actually "drill itself in" for some distance, i.e., bits of rock would be broken off by the gas stream and fly up the drill hole past the bit. It is a very risky business drilling into a high pressure pool like this without any pressure control other than the weight of the drilling tools, and in several cases in the past, tools have actually been blown right out of the hole. As the early pools (Dawn 47-49 and 59-85) were produced and the pressure dropped, it became safe to move a cable-tool rig back on to deepen the holes and improve deliverability. This was done several times, and deep, clean holes were finally achieved which are even today some of the best wells we have.

HOWEVER, to complete a deep well in such a pool at high pressure, it was necessary to go to rotary drilling tools, where pressure control is possible by the use of weighted mud in the hole, and blow-out prevention equipment at the wellhead. The big disadvantage however was the fact that the mud itself, and materials added to it to prevent loss of the mud into the formation, filled and clogged the pores of the formation where they were need most - at and near the surface of the well-bore. Some means had to be found to obtain a clean deep hole, and at the same time control pressures and gas flow during drilling. In 1957, a new well-completion method was planned and first tried, with great success. Wells were to be drilled to the casing-point just above the gas-reservoir, either with cable tools, or with rotary tools using mud (we have done it both ways). After the casing was set and cemented, rotary tools were to penetrate to the required depth in the reservoir, but using gas as the drilling medium rather than mud.[14] It served most of the same purposes as mud (such as cooling the bit and returning cuttings to the surface), except for controlling the gas pressure. This was to be done with specially designed control equipment supplied and operated by Otis Pressure Control, Inc., Dallas, Texas. In simplest terms, the method was as follows: A supply of gas for the drilling fluid was obtained from a nearby producing well and circulated in the same way as mud, down the drill pipe and up the annular space between the drill pipe and the wall of the hole. Drilling was done through a Schaeffer rotary control head which permitted the drilling tools to pass through, but diverted gas returning from the hole to a 7-inch flow line which carried the gas several hundred feet away for release to the atmosphere. Here it was measured with a pitot-tube to determine the increase in flow rate with depth. Figure 11 shows a side view of part of the drilling-rig, the drilling head, and flow line. Drilling was generally very fast (commonly averaging 5 to 10 minutes per foot), in comparison with standard methods and loss of gas was thereby kept to a minimum. The Otis equipment was required when running tools in and out of the hole and placing tubing. This equipment did its job by means of two snubbers above the rig floor which clamped to the pipe in turn and passed it through two hydraulically-operated blow-out preventers which contained the gas pressure, and operated alternately to allow passage of pipe collars without leakage or loss of control of the pipe. Figure 12 shows this equipment in use on one of Union's storage wells.

A classic example of the effectiveness of gas drilling is the comparison of two adjacent wells in our Payne pool. Payne 11 was drilled with rotary tools using mud, and completed on July 20, 1957. The well penetrated 118 feet into the gas reservoir, yet even after acidizing, tests showed an open flow deliverability of only 25,000 Mcf per day at maximum pressure. Payne 12 was our first experience with gas drilling. This hole was drilled to the casing-point using mud, but drilled into the reservoir with gas. It was located only 590 feet, to the northeast of Payne 11, and was completed on August 16, 1957. Although the well penetrated only 39 feet of the same gas reservoir, or one-third as much as Payne 11, its open flow deliverability at maximum pressure is 95,000 Mcf per day, almost four times as great. Although gas drilling is somewhat more expensive by the foot than conventional drilling, it has been demonstrated its ability to give us the equivalent of almost four wells for little more than the price of one.

IN completing the wells, all casing was cemented to the surface for additional strength. Our most recent wells contain tubing, as an added safety factor and to ensure control of the well under all conditions. Figures 13, 14 and 15 illustrate the wellhead control equipment ("Christmas-trees") on three different wells. The well in Figure 13 is tubed, and is typical of more recent completions. That in Figure 14 is normally an observation well. The recording pressure gauge can be seen here, as well as some of the equipment used for cathodic corrosion-protection of wellhead and casing.

SOME reservoir engineering data ordinarily obtainable by direct measurement and examination are not readily acquired when drilling with gas. Rock samples, for example, are very fine and difficult to obtain. However, since the main objective in drilling storage wells is to achieve high deliverability, it would seem unwise to sacrifice it to obtain much information of academic interest, but often of doubtful practical value. All important operating characteristics and some knowledge of physical properties can be obtained, in any case, by means of various tests on storage wells after completion, and during operation.

SUFFICIENT additional drilling by conventional means should be done in a storage area, however, to obtain representative core samples for geological examination and core-analysis, to determine the depth of the base of the gas cap, and to test for commercial oil. Such additional drilling may be especially useful when it is necessary to observe or control the movement of bottom-water, or where more detailed knowledge is required of changes in the nature of the reservoir rock with depth or lateral extent, particularly in larger, less permeable reservoirs.

IT is common practice in operating any type of storage pool to have certain wells normally shut-in, where pressures can be gauged (or fluid levels observed), under static conditions. Union maintains at least one well in each of its pools for such purposes. Each has a recording pressure gauge connected to it and in addition pressures are gauged at least once a week using the more accurate dead-weight gauge. In most cases these observation wells are connected to the gathering system, too so that for short periods of peak demand they can be opened up to contribute to the deliverability of the field.

THE rate at which a storage pool can deliver gas is probably the greatest single factor contributing to its importance in the industry. Figure 16 illustrates the use made of storage by Union Gas in meeting peak loads. On the average, Union's pools have delivered 65.2% of the total demand on the system during the peak day each winter for the past 10 years.

THE storage engineer employs essentially the same methods and equipment long familiar to every production and transmission engineer, such as pipeline flow formulas, metering, horsepower curves, and dispatching techniques. The big difference is in the rate of gas production he must deal with, and this is determined by the performance of the reservoir and its wells.

WHERE a normal gas field is usually developed and produced in such a way that its reserved can be recovered over a period of about 20 years, or some 7,000 days, a storage pool is expected to produce more than halp of its total capacity in a period of 150 days or less. Further, the maximum rate of delivery required of a storage pool in this period may well exceed 2% of the total recoverable reserves. Figure 17 shows, for the year 1961-62, turnover of storage gas by Union in comparison with load, and the effectiveness of storage in balancing seasonal supply and demand. A most important requirement of storage pool therefore is that it must be able to produce in from 100 to 150 days, a volume which may have taken up to 7 months to inject.

THE engineer must be able, from a knowledge of the reservoir and the flow of gas within it, to determine the extent of pressure differentials set up by high rates of flow. He must be able to determine the maximum rate that can safely be achieved at any given set of pressure conditions, and how long this rate can be sustained. This again is especially important in late-season cold snaps, when it may be necessary for short periods to operate all facilities at peak capacity. An unexpected drop in compressor suction pressure at such a time, due perhaps to unknown flow conditions in a so storage reservoir, could be very serious.

THERE is a limit to the rate at which gas can safely be produced from a storage well. In thin reservoirs underlain by water-saturated rock strata, the drop in pressure near a well caused by too rapid withdrawal could result in the water level being raised at this point, or "coned". Water could enter the well and thus the gas-stream, perhaps drown the well, or permanently plug off part of the reservoir. Too rapid withdrawal could, in cases where the reservoir rock is poorly-consolidated, also cause bits of rock to break off and be carried out of the well in the gas stream, causing abrasion to pipe and fittings, or other damage. For these and other reasons, most operators impose limits on withdrawal rate, usually by setting a maximum pressure differential, or ratio of pressures, between a shut-in over observation well and a flowing well.

THE relative ability of the reservoir to produce gas has a profound effect on the economics of every phase of the project. It, along with the method of completion, will determine how many wells will be required to produce the working gas within the winter season, and to what extent the peak demands can be met from these wells. In turn, the volumes to be handled and the deliverability of the pool will affect the sizing, design and cost of other surface facilities such as gathering lines, storage lines, measurement and regulation equipment, compressor plant and transmission lines. Figure 18 is an overall view of a part of Union's Dawn compressor-station and gas dispatching control centre. Figure 19 is a view of two of the newer compressors at Dawn station used for pumping gas to storage. These are Clark turbocharged TLA-6 engines, rated at 2000 horsepower each.

Deliverability Tests

BECAUSE of the fundamental, importance of deliverability in the operation and economics of storage, a reliable method of determining the rate of flow which can be obtained and sustained from a well under any given set of pressure conditions is essential. The so-called back-pressure method of gauging wells is probably the best way to do this, particularly in high capacity wells in permeable reservoirs.[15] Although this procedure is far from new, the older method of gauging wells by means of an "open flow can" is still in widespread use. In this latter method, the open flow capacity of a well is measured by allowing the well to flow wide open through a large orifice until it reaches a steady rate, and then gauging the pressure differential across the orifice. Much gas is needlessly wasted when the method is used to test a large well, and the knowledge of its capacity is limited. There is no indication of how the well will behave under normal operating conditions, against different line pressures and at lower reservoir pressures. However, the method is still justified to some extent in smaller wells, say less than 3,000 Mcf/day capacity, because the accuracy of the back-pressure method is less reliable in this range.

FIGURE 13 illustrates a typical set-up for a back-pressure test. In simplest terms, the method determines the well's ability to produce against a range of pressures. This is done by inserting one after another, a series of small-diameter orifice plates, which act to restrict the flow in varying degrees, into a special tubular-steel container called a critical-flow prover.

THE flow characteristics determined with each orifice plate is a complete test in itself of the well's deliverability under specific conditions, but a series of them together is much more meaningful. Figure 20 shows a set of deliverability curves for the Payne pool. Each well has its own curve, which incorporates all the information from a back-pressure test. Also shown in this is a single curve, which indicates the field deliverability obtainable at the well-head when all wells are produced together, by combining the results of all tests. The position of each curve on the graph tells us the relative capacity of the well compared to others, its ability to produce under any given pressure conditions, and also, by the slope of the surve, something about the characteristics of the reservoir rock itself. Since the method gives the most information, is most accurate for larger wells, and yet keeps loss of gas in testing to a minimum, its use is recommended whenever possible. (16) (17) (18).

A more recent variation of the back-pressure test, the isochronal method, has been devised for use in testing wells where flow conditions take longer to stabilize because of less permeable reservoir rock. (19) (20)

THE tests described tell us the producing characteristics of the wells, and allow us to predict deliverability at the well-head. However, they do not give us sufficient knowledge of what we can expect from a pool at the compressor station, or other main control point several miles from the pool. To do this we must take into account the varying flow characteristics of the entire system of wells, gathering-lines, main storage lines and other equipment affecting flow. In operating storage, we must constantly and speedily be able to determine what a complete storage facility can do for us at the station under every set of conditions, and ensure that it is not operated beyond safe limits. We have therefore devised a set of operating curves for each pool that will do this for us. Figure 21 shows such a set of curves for Union's Payne pool. From these we can tell immediately what the pool will do, when we know the pressure at a shut-in observation well, at any given flowing pressure (usually the compressor suction pressure) at the plant. They can be derived by combining back-pressure curves and standard pipe-line flow curves, with allowance for valves, bends and other flow restrictions. Where possible, however, it is probably better to draw the curves in empirically, that is, from actual data obtained under operating conditions.

Conclusion

THE business of storing gas underground, although it has already reached significant proportions, is really still in its infancy. If the past is a reliable indicator of future growth we can expect to see ever-increasing use of storage throughout the gas industry. Its growth will require careful long-range planning, in order to keep in step with the greater consumption, variety of applications, and especially within the increasing fluctuations in hourly, daily and seasonal demand for this versatile fuel.

THE many advantages to all concerned: the long-line transmission companies, gas utilities and their customers, are such that continuous development of new pools is bound to take place, in Ontario as elsewhere, as the need for more space becomes evident.

ALSO, with advances in engineering techniques, especially in the fields of development and operation, a greater variety of geological structures can be economically adapted to storage reservoirs. The prospects in this regard in Southwestern Ontario appear to be quite favourable.

THIS presentation has been an attempt to take a broad look at many aspects of storage, with the hope that it might lead to a better overall understanding of this fascinating enterprise.

REFERENCES

(1) AMERICAN GAS ASSOCATION; COMMITTEE ON UNDERGROUND STORAGE;: "The Underground Storage of Gas in the United States"; December 31st, 1961; Eleventh Annual Report on Statistics.

(2) BIZAL, ROBERT B.: "Gas Storage Capacity Spurts", The Oil and Gas Journal, May 14, 1962, /p. 125.

(3) DAVIS, RALPH E.: "Economics of Natural Gas Storage," Gas, May 1951, p. 103.

(4) MURDY, RICHARD J.: "Physical Aspects of Underground Storage", Presented at National Conference of Electric and Gas Utility Accountants, Boston, Mass., April 1954.

(5) MARTINSON, E. VINCENT: "Review of Aquifer Gas Storage Projects," Presented at Transmission Conference, Operating Section, American Gas Association, Denver, Colorado, May 1961.

(6) BLEAKELY, W. B.: "Old Coal Mine Converted to Gas Storage", The Oil and Gas Journal, December 18, 1961, p. 88.

(7) "HERSCHER DOME: STORAGE DESPITE LEAK,": The Oil and Gas Journal, August 18, 1958, p. 114.

(8) MILLER, C. C., DYES, A.B. & HUTCHISON, C. A. Jr.: Estimation of Permeability and Reservoir Pressure from Bottom Hole Pressure Build-up Characteristics," AIME Transactions, 1958, p. 213

(9) MATTHEWS, C. S.,: "Analysis of Pressure Building-up and Flow Test Data", Journal of Petroleum Technology, September 1961, p. B-47.

(10) WANSBROUGH, R. S.: "How to Evaluate Gas Well Damage by Pressure Build-up Tests," The Petroleum Engineer, Sept. 1957, p. B-47.

(11) VAN EVERDINGEN, A. F.: "The Skin Effect and its Influence on the Productive Capacity of a Well", AIME Transactions, 1953, p. 198.

(12) WILLIAMS, R. R.: "Well-bore Damage and Transmissibility at Wellsite", Canadian Oil and Gas Industries, December, 1960, p. 35.

(13) WATERS, A.B., and AYRES, H.J.: "Gas Storage Well Deliverability Boosted by Fracturing", Pipe Line Industry, August 1958, p. 32.

(14) HOLLIS, W. J.: "Drilling Wells with Gas as a Circulating Medium Instead of Mud", Presented at Gas Supply, Transmission and Storage Conference, American Gas Association, New Orleans, Louisiana, March 1954.

(15) RAWLINS, E.L., and SCHELLHARDT,M.A.: "Back-Pressure Data on Natural Gas Wells and Their Application to Production Practices", U. S. Bureau of Mines, Monograph 7, 1935.

(16) WALKER, C.J., CORLISS, E.R.,MILLER, J.S. and DUNNING H.N.: "Deliverability Tests on Gas Storage Projects", A.G.A. Paper G STS-57-5, Presented at Transmission Conference, American Gas Association, San Francisco, Calif., May 1957.

(17) WALKER, C.J., MILLER J.S., and DUNNING, H.N.: "Back-Pressure Tests on Gas-Storage Projects", A.G.A. paper GSTS-60-4, Presented at Operating Section Conference, American Gas Association, 1960.

(18) COOK, RICHARD G.: "Predicting Delivery Rates from Underground Storage Projects," Gas, February, 1959, p. 59.

(19) VARY, J.A., ELENBAAS, J.R.&WITHROW, H.J.: "Input Flow Test Method Determination of Well Performance", Presented at Research Conference on Flow of Natural Gas from Reservoirs, University of Michigan, Ann Arbor, Michigan, June 1955.

(20) CULLENDER, M.H.: "Methods of Determining the Flow Characteristics of Gas Wells," The Canadian Mining and Metallurgical Bulletin, March, 1961.

OTHER REFERENCES' AND RECOMMENDED READING

(21) TODD, RAYMOND W.: "The Development of Underground Storage in the Pacific Coast Gas Industry," A.G.A. paper GSTS-57-51, Presented at Transmission Conference, American Gas Association San Francisco, Calif., May, 1957.

(22) FERGUSON, W.E.,: "The Development and Operation of an Underground Storage Program - The Benton Project of the Ohio Fuel Gas Company," A.G.A. paper TS-53-6, Presdnted at Transmission and Storage Conference, American Gas Association, Chicago, Ill., April, 1953.

(23) VARY, JOHN A.: "Engineering Aspects of Underground Storage", Gas Age, August 18, 1960, p. 42.

(24) TEK, M.R.: "Developments in Natural Gas Reservoir Engineering", ThePetroleum Engineer, March, 1959, p. B-47.

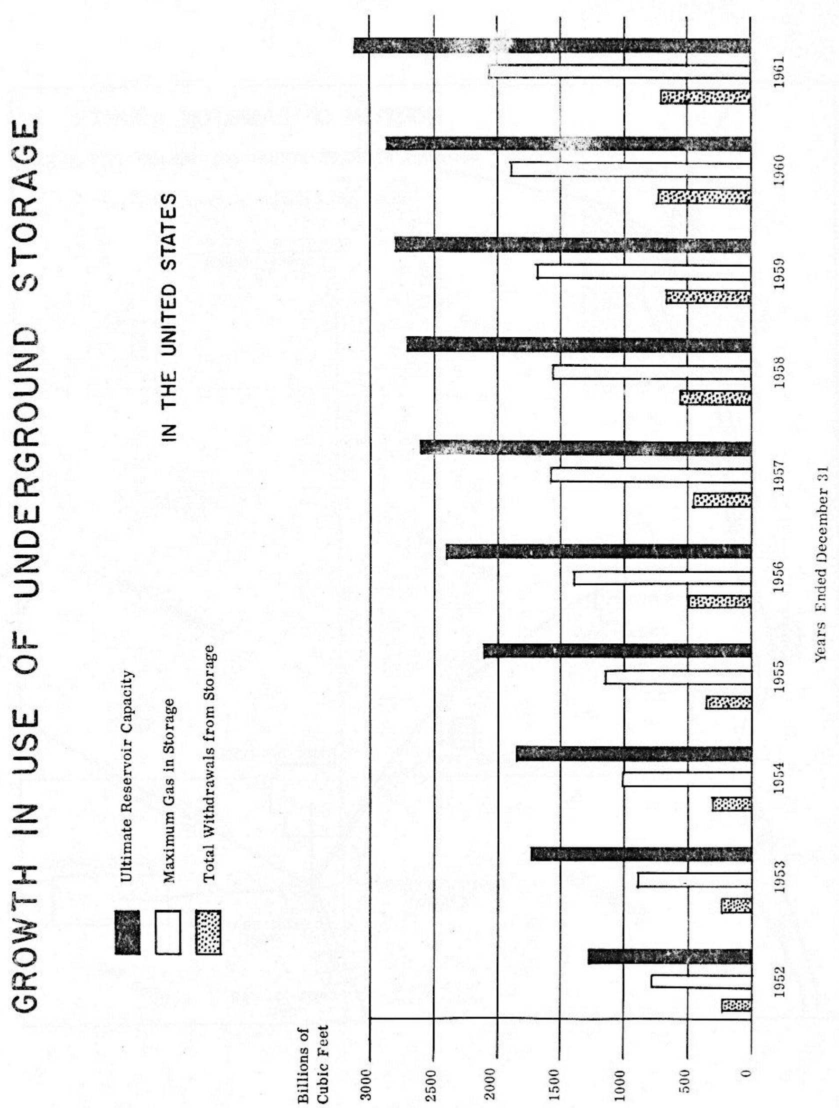
(25) KATZ, Donald L.; CORNELL, DAVID; VARY, JOHN A., et al: "Handbook of Natural Gas Engineering", McGraw-Hill Book Co., Inc., 1959.

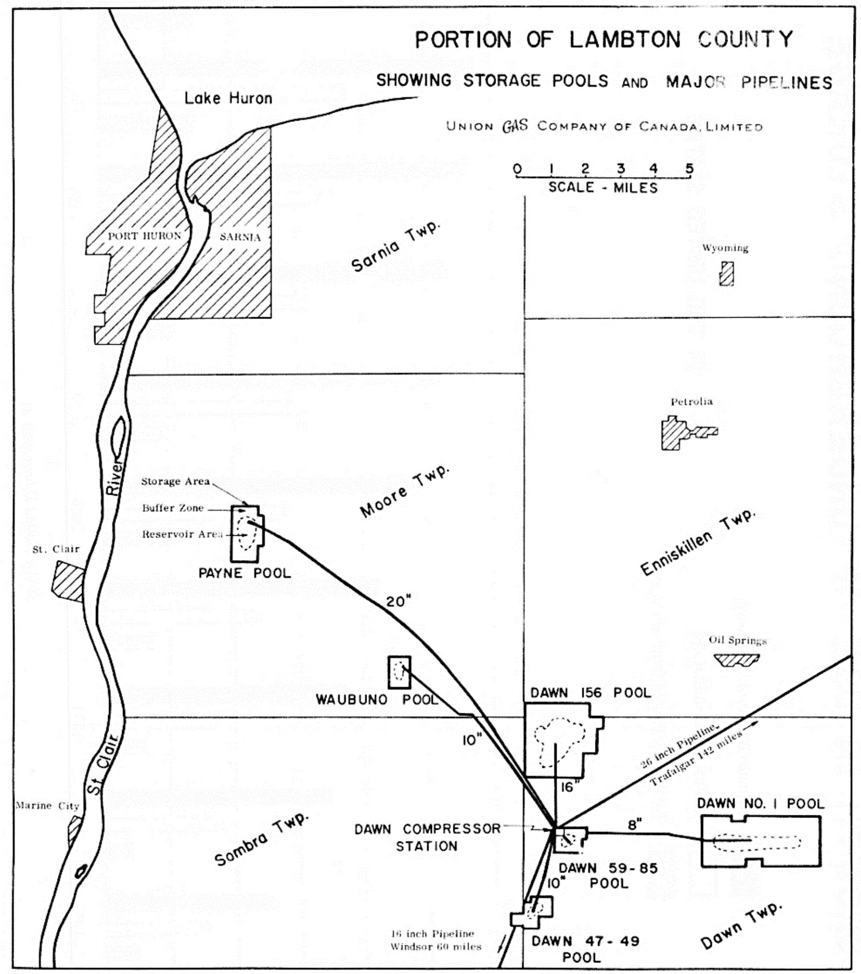
(26) CHARBONNIER, R. P.: "Present Status of Underground Storage of Natural Gas in Southern Ontario and Quebec", Canada Department of Mines and Technical Surveys, Ottawa; Mines Branch. Information Circular IC-121, May, 1960.

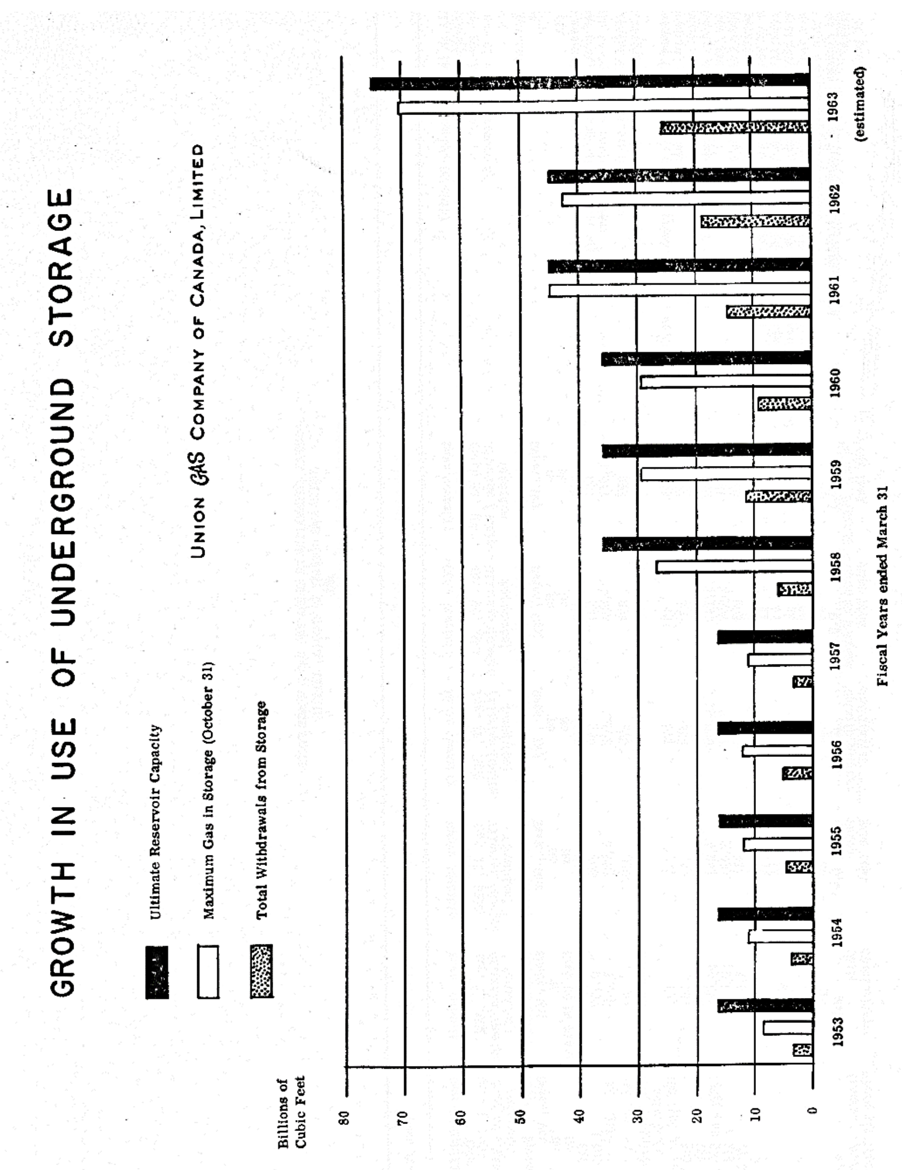
(27) CHARBONNIER, R. P.: "Selected Abstracts on Underground Storage of Gas", Canada Department of Mines and Technical Surveys, Mines Branch, Ottawa; Fuels and Mining Practice Division, Internal Report FMP60/206-PRE, December, 1960.

(28) WALLACE, B. J.: "Bibliography of Underground Storage and Related Subjects", Canadian Gas Association, Committee on Production and Storage, April, 1961.

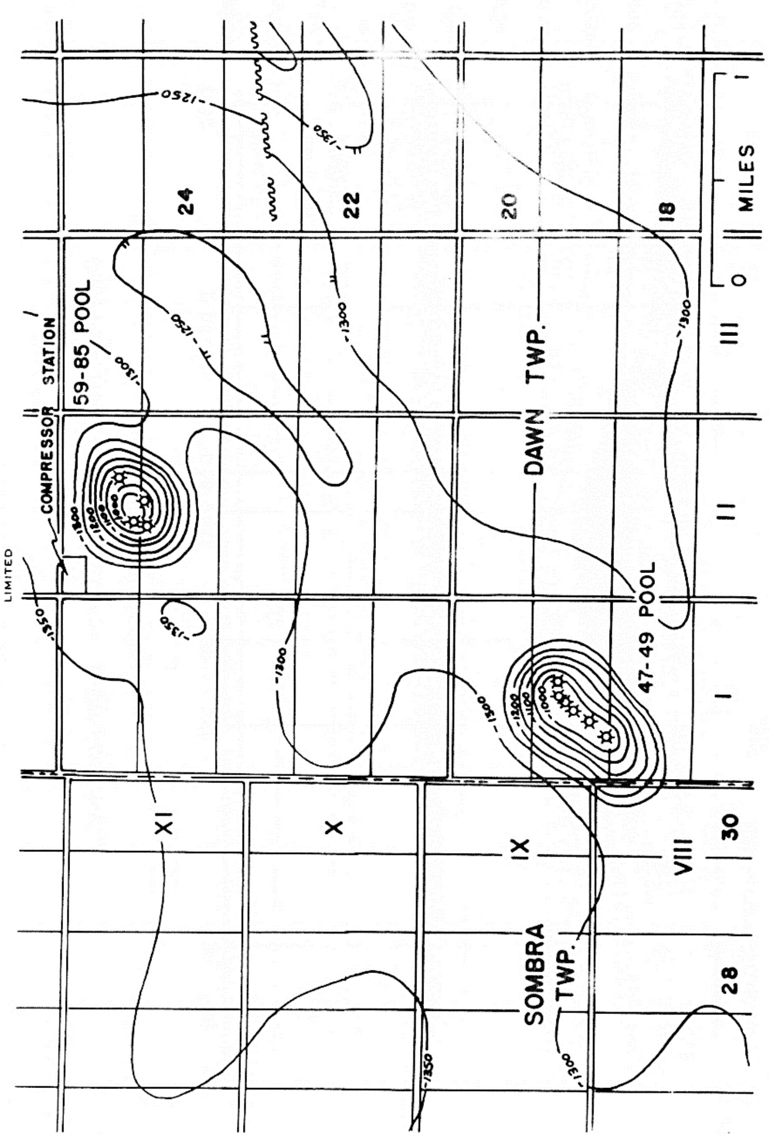
(29) "Bibliography on Underground Gas Storage", American Gas Association (OP-59-4), compiled by Committee on Underground Storage, July 1, 1959, and later supplements.


GROWTH IN USE OF UNDERGROUND STORAGE
IN THE UNITED STATES
Ultimate Reservoir Capacity
Maximum Gas in Storage
Total Withdrawals from Storage
Billions of Cubic Feet
3000
2500
2000
1500
1000
500
0
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
Years Ended December 31


PORTION OF LAMBTON COUNTY
SHOWING STORAGE POOLS AND MAJOR PIPELINES
UNION GAS COMPANY OF CANADA, LIMITED
0 1 2 3 4 5
SCALE - MILES
Lake Huron
PORT HURON
SARNIA
Sarnia Twp.
Wyoming
Petrolia
Storage Area
Buffer Zone
Reservoir Area
Moore Twp.
Enniskillen Twp.
St. Clair
PAYNE POOL
20"
Oil Springs
WAUBUNO POOL
DAWN 156 POOL
10"
River
St. Clair
26 inch Pipeline
Trafalgar 142 miles
16"
Marine City
DAWN NO. 1 POOL
Sombra Twp.
DAWN COMPRESSOR STATION
8"
DAWN 59-85 POOL
10"
16 inch Pipeline
Windsor 60 miles
DAWN 47-49 POOL
Dawn Twp.

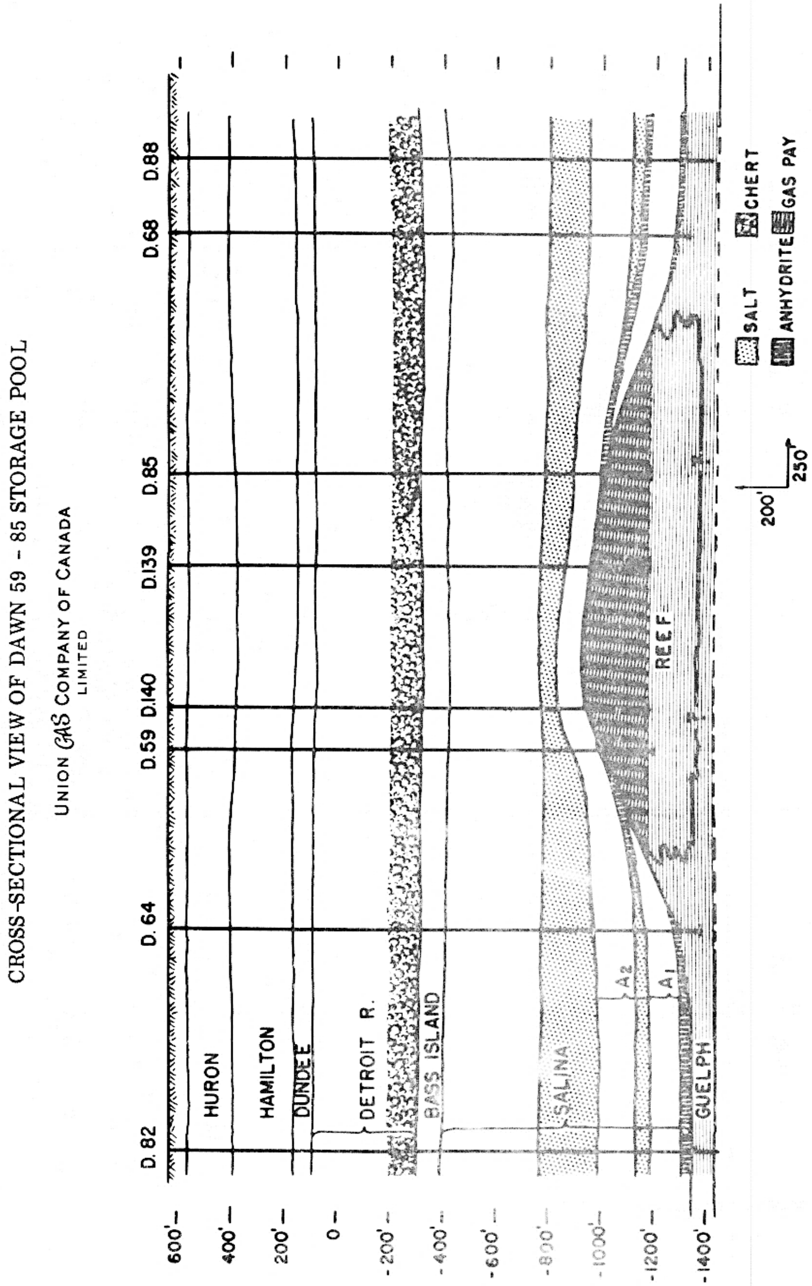


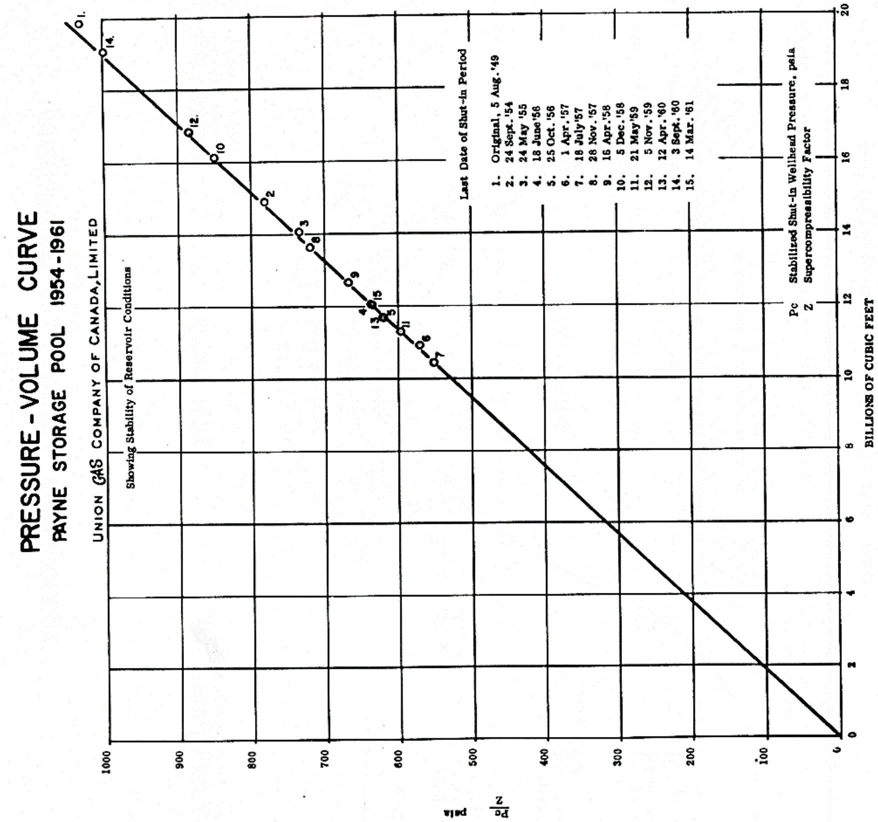
CONTOUR MAP DRAWN ON THE SURFACE OF THE GUELPH FORMATION
SHOWING TWO REEF STORAGE POOLS
UNION GAS COMPANY OF CANADA, LIMITED



GENERAL INFORMATION ON OPERATING GAS STORAGE POOLS
UNION GAS COMPANY OF CANADA, LIMITED
AND
ONTARIO NATURAL GAS STORAGE AND PIPELINES, LIMITED

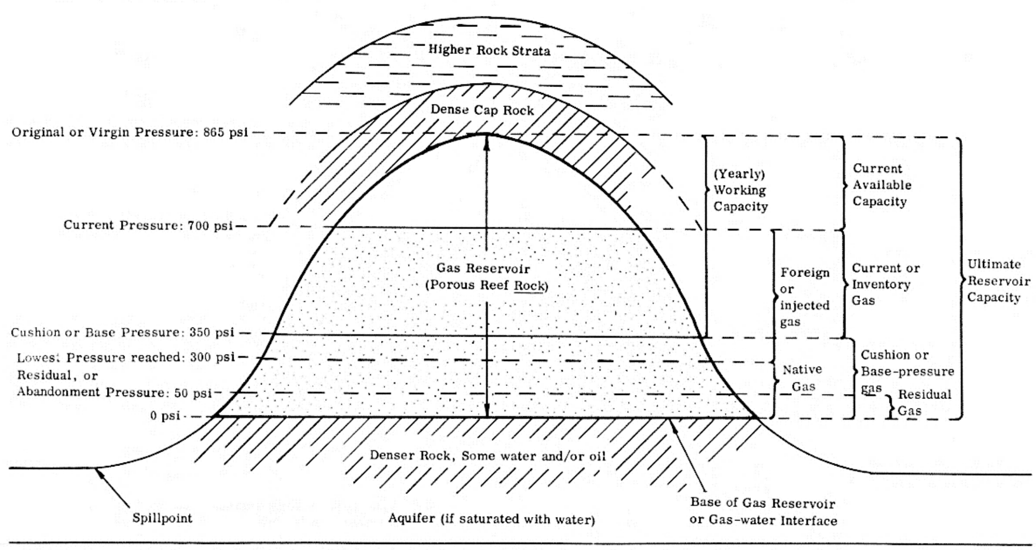
	Dawn 59-85	Dawn 47-49	Payne	Waubuno	Dawn 156	Dawn No. 1
Location (all in Lambton County, Ontario)	Dawn Township	Dawn Township	Moore Township	Moore Township	Dawn Township	Dawn-Enniskillen Twps.
Year of discovery	1931	1930	1949	1951	1952	1914
Date of first gas injection	March 31, 1943	Oct. 28, 1942	Aug. 22, 1957	Aug. 18, 1960	Aug. 1, 1962	Oct. 1, 1954
Geological age of storage reservoir	Silurian (Guelph formation	Silurian (Guelph formation)	Silurian (Guelph formation)	Silurian (Guelph formation)	Silurian (Guelph formation)	Silurian (Salina formation)
Type of structural trap	Bioherm (Reef)	Bioherm (Reef)	Bioherm (Reef)	Bioherm (Reef)	Bioherm (Reef)	Fault - Porosity
Original gas	Sweet, Dry	Sweet, Dry	Sweet, Dry	Sweet, Wet	Sweet, Wet	Sweet, Wet
Water-drive	No	No	No	No	No	No
Commercial oil	No	No	No	No	Some on NW Flank	No
Area of gas reservoir, acres	163	187	369	164	804	642
Total storage area, including buffer zone, acres	450	525	750	506	2,730	3,100
Minimum depth to top of gas reservoir, feet	1,579	1,601	1,963	1,823	1,646	'A_2' 1542; 'A_1' 1713
Maximum thickness of gas reservoir, feet	297	254	378	339	348	'A_2' 20; 'A_1' 9(avg.)
Performance rating (function of effective porosity & permeability	Excellent	Fair	Excellent	Good	Excellent	Poor (requires well stimulation)
Original pressure (present max. storage press.) psig., wellhead	865	865	877	931	877	760 (500 present max.)
Curshion pressure, psia (wellhead)	500	350	350	350	350	300
Lowest pressure reached psig (wellhead)	25	111	479	418	648	176
Ultimate capacity of storage reservoir, MMcf	8,662	5,331	19,586	9,247	29,871	1,995 (at 500 psig)
Cushion volume, MMcf	4,651	1,954	7,057	3,093	10,436	1,119
Non-recoverable (residual) gas, MMcf	429	263	955	418	1,340	178
Number of operative injection wells	4	6	8	6	8	6
Total number of wells drilled to Silurian in storage area	13	11	15	13	27	18
Field deliverability at maximum pressure (80% back-pressure) MMcf/day	183	44	200	92	219	2
Field deliverability at cushion pressure (80% back-pressure) MMcf/day	107	14	65	31	77	0.5
Total combined maximum open flow of storage wells, MMcf/day	300	85	370	162	395	5
Diameter of main storage pipeline, inches	10	10	20	10	16	8
Distance from storage pool to compressor station, miles	0.5	2.5	12.7	6.4	2.7	4.5
Operating company	Ontario Storage	Ontario Storage	Ontario Storage	Union	Union	Ontario Storage
Primary use of pool	Peak Load	Base Load	Combination	Base Load	Combination	Presently inactive


CROSS-SECTIONAL VIEW OF DAWN 59 - 85 STORAGE POOL
UNION GAS COMPANY OF CANADA LIMITED
D.82
D.64
D.59
D.140
D.139
D.85
D.68
D.88
HURON
HAMILTON
DUNDEE
DETROIT R.
BASS ISLAND
SALINA
A2
A1
GUELPH
REEF
SALT
ANHYDRITE
CHERT
GAS PAY
200'
250'
600'
400'
200'
0
-200'
-400'
-600'
-800'
-1000'
-1200'
-1400'


PRESSURE - VOLUME CURVE
PAYNE STORAGE POOL 1954-1961
UNION GAS COMPANY OF CANADA, LIMITED
Showing Stability of Reservoir Conditions
Last Date of Shut-in Period
1. Original, 5 Aug.'49
2. 24 Sept.'54
3. 24 May '55
4. 18 June'56
5. 25 Oct.'56
6. 1 Apr.'57
7. 18 July'57
8. 28 Nov.'57
9. 16 Apr.'58
10. 5 Dec.'58
11. 21 May'59
12. 5 Nov.'59
13. 12 Apr.'60
14. 3 Sept.'60
15. 14 Mar.'61
Pc Stabilized Shut-in Wellhead Pressure, psia
Z Supercompressibility Factor
BILLIONS OF CUBIC FEET
Pc/Z psia

UNDERGROUND GAS STORAGE TERMINOLOGY

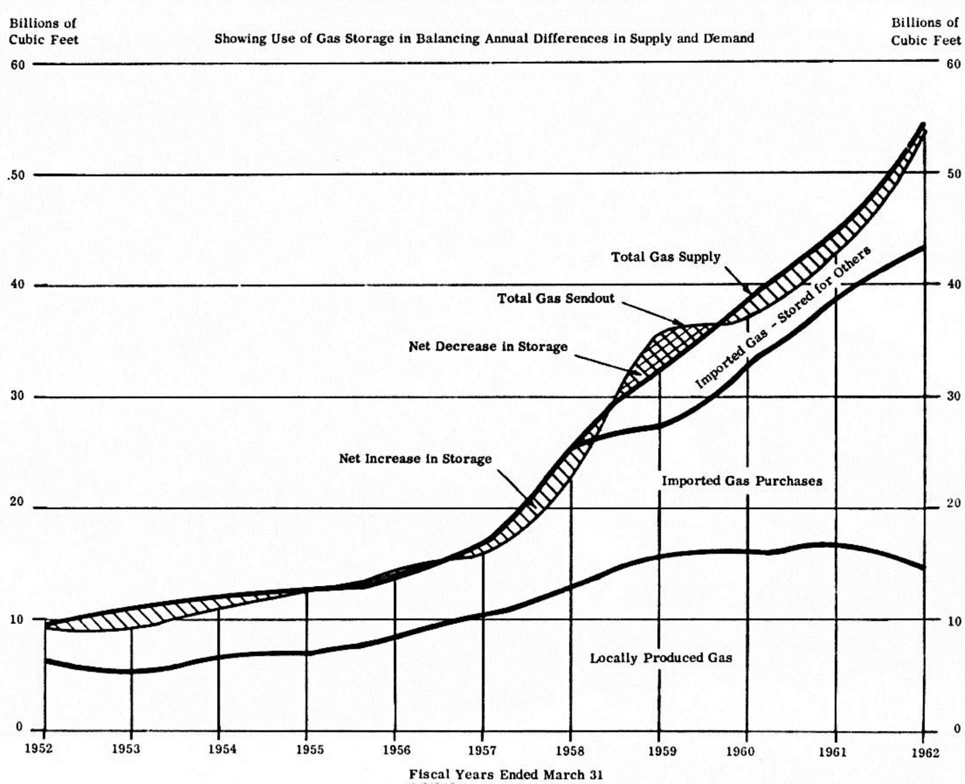
(Diagrammatic)



Note: The diagram illustrates gas as if it were a liquid. Actually, the reservoir is filled with gas at any pressure above 0 psi.

ANNUAL GAS SUPPLY AND SENDOUT - 1952-1962

UNION GAS COMPANY OF CANADA, LIMITED



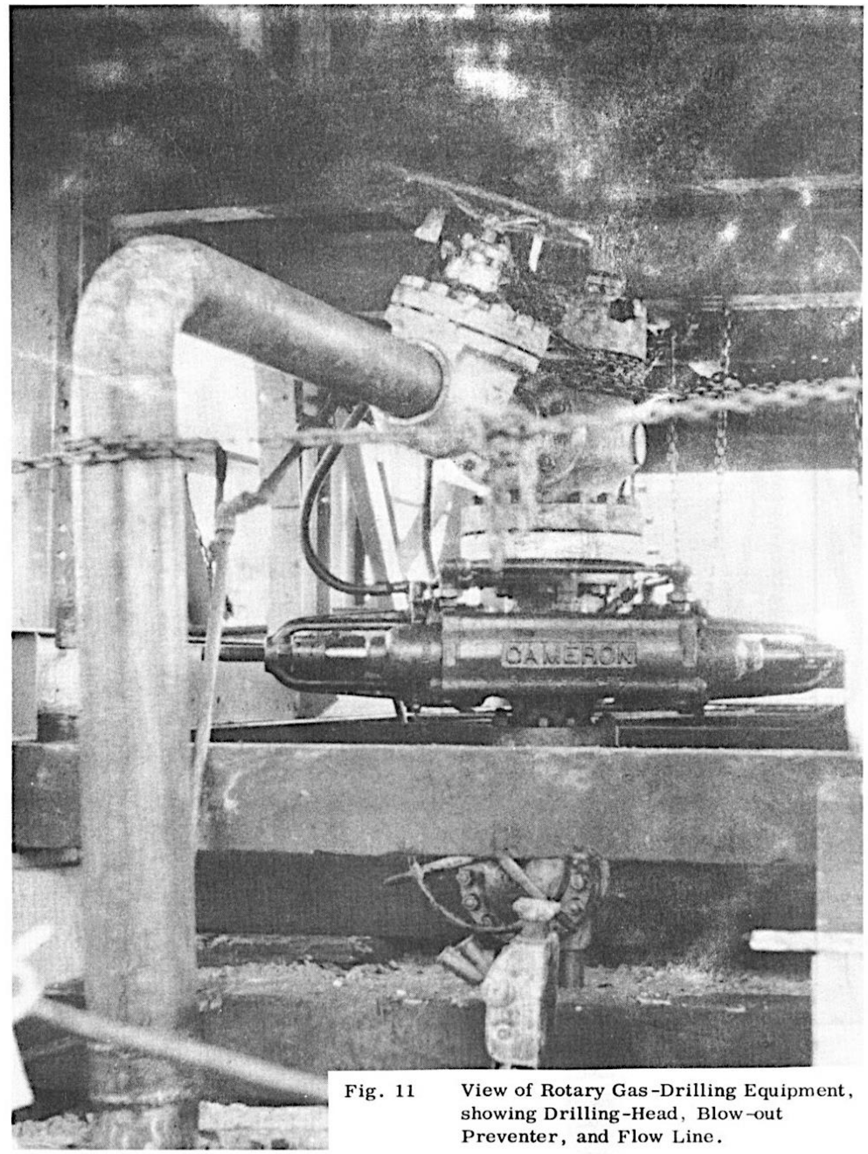
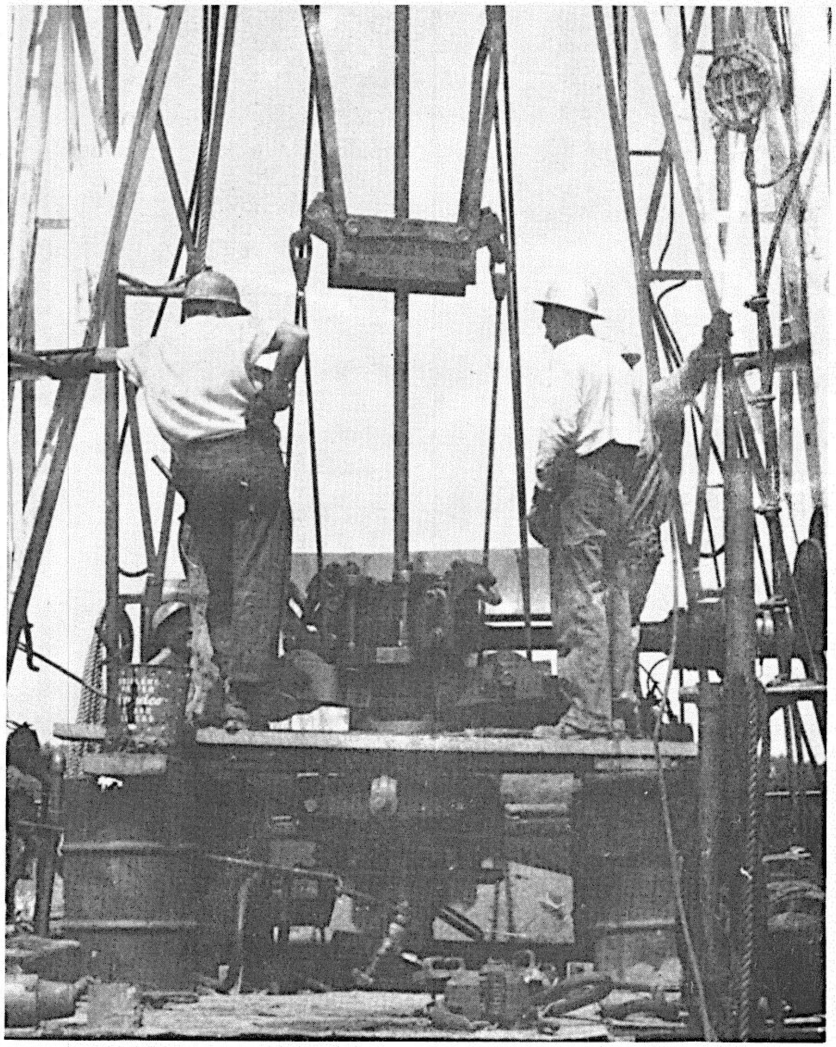


Fig. 11 View of Rotary Gas-Drilling Equipment, showing Drilling-Head, Blow-out Preventer, and Flow Line.



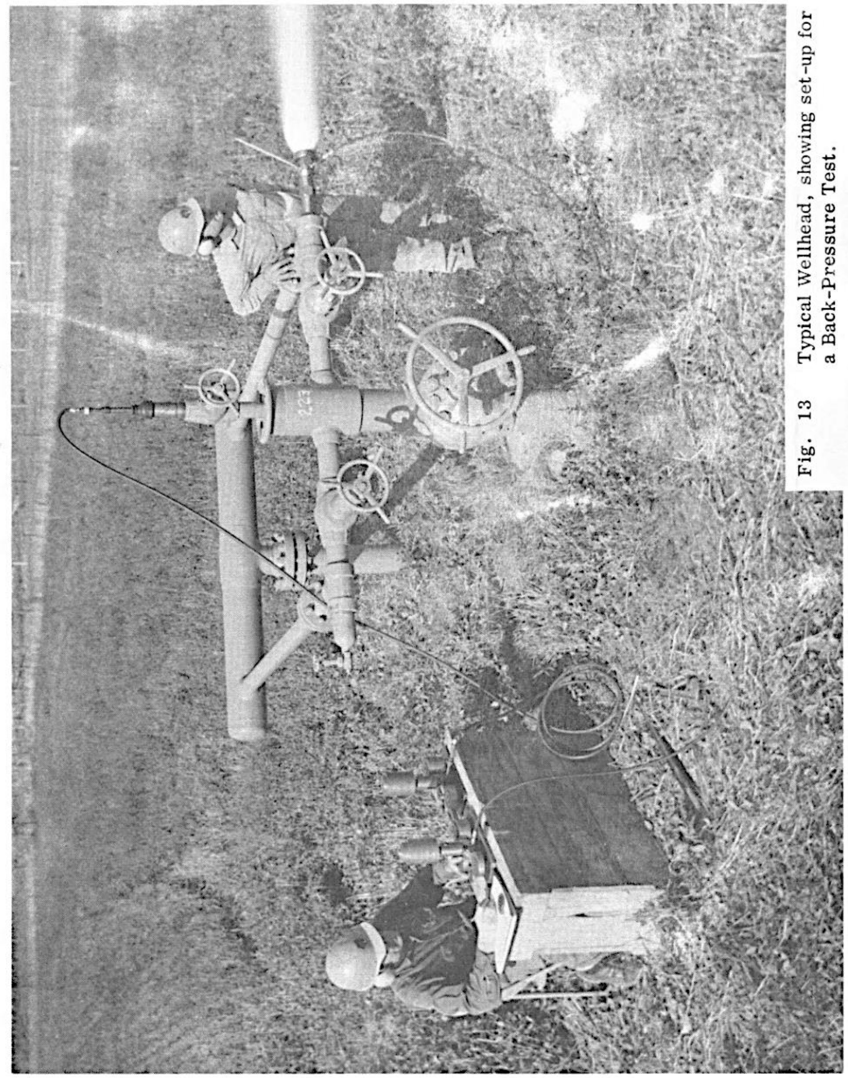
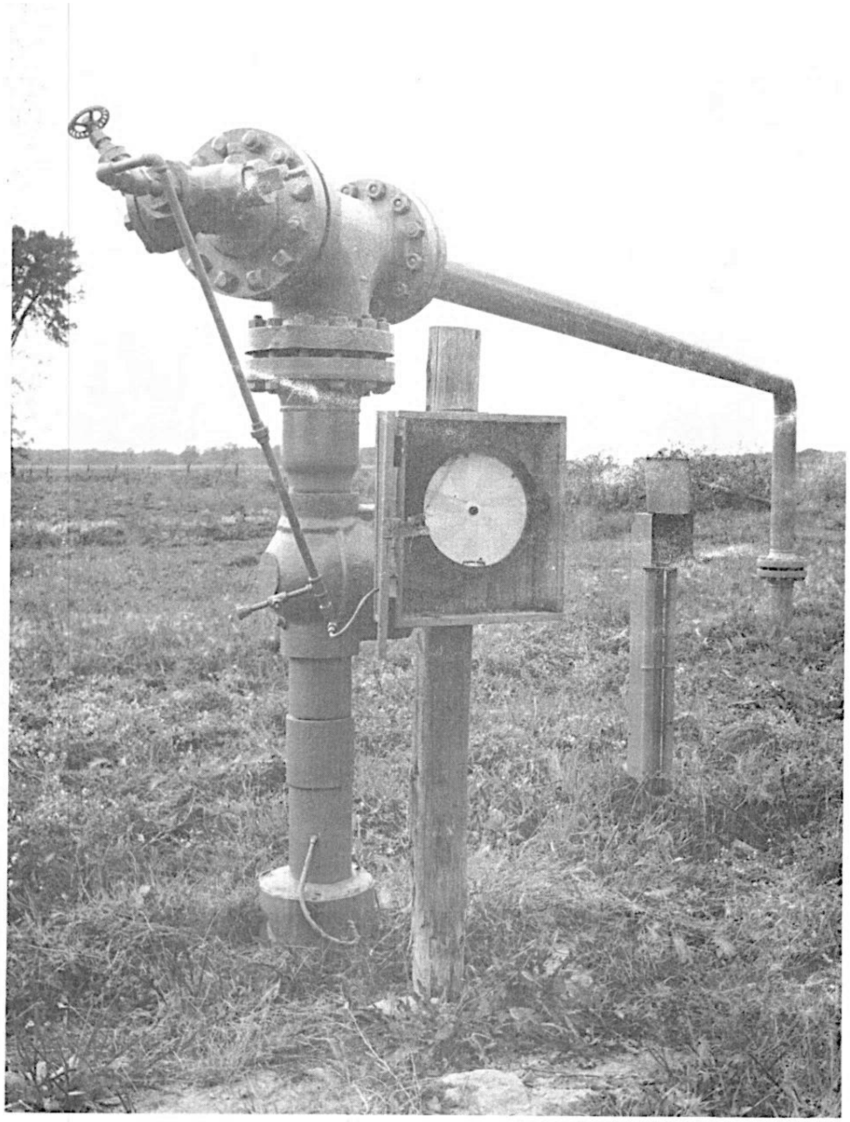


Fig. 13 Typical Wellhead, showing set-up for a Back-Pressure Test.



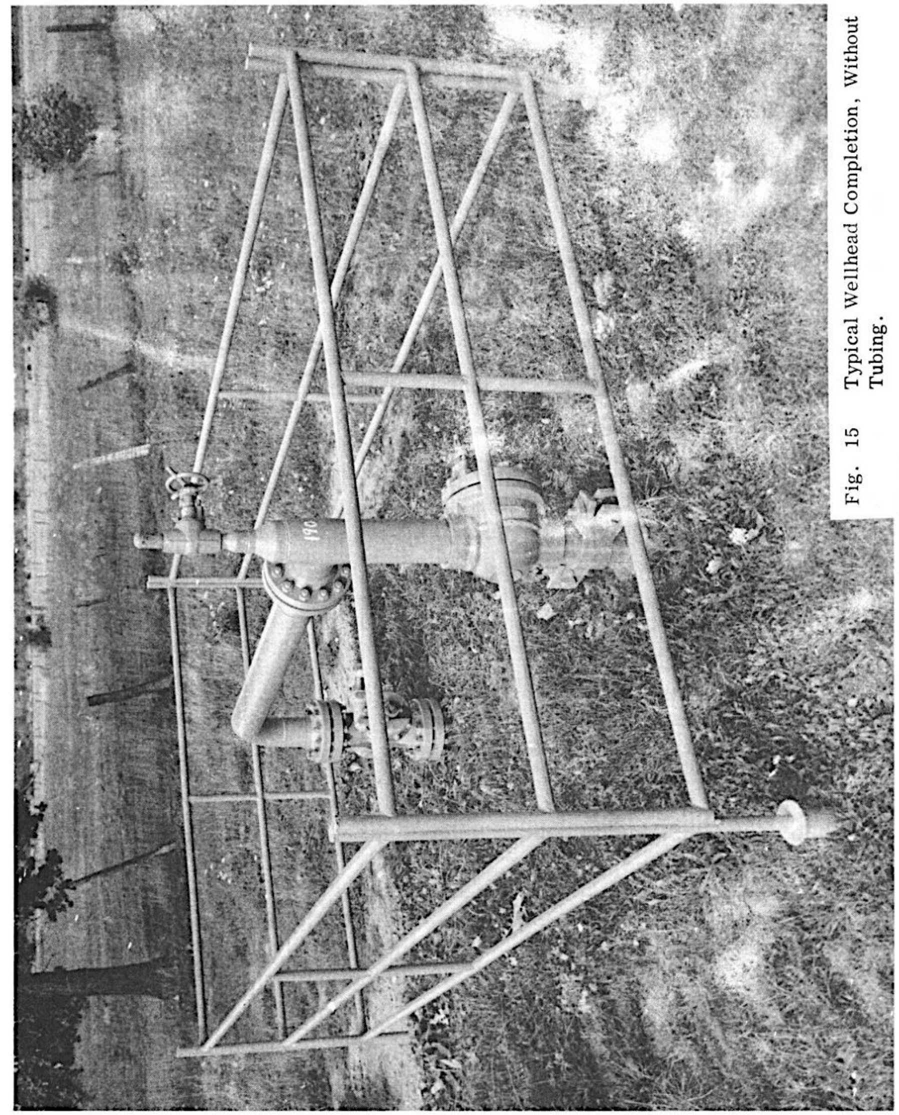
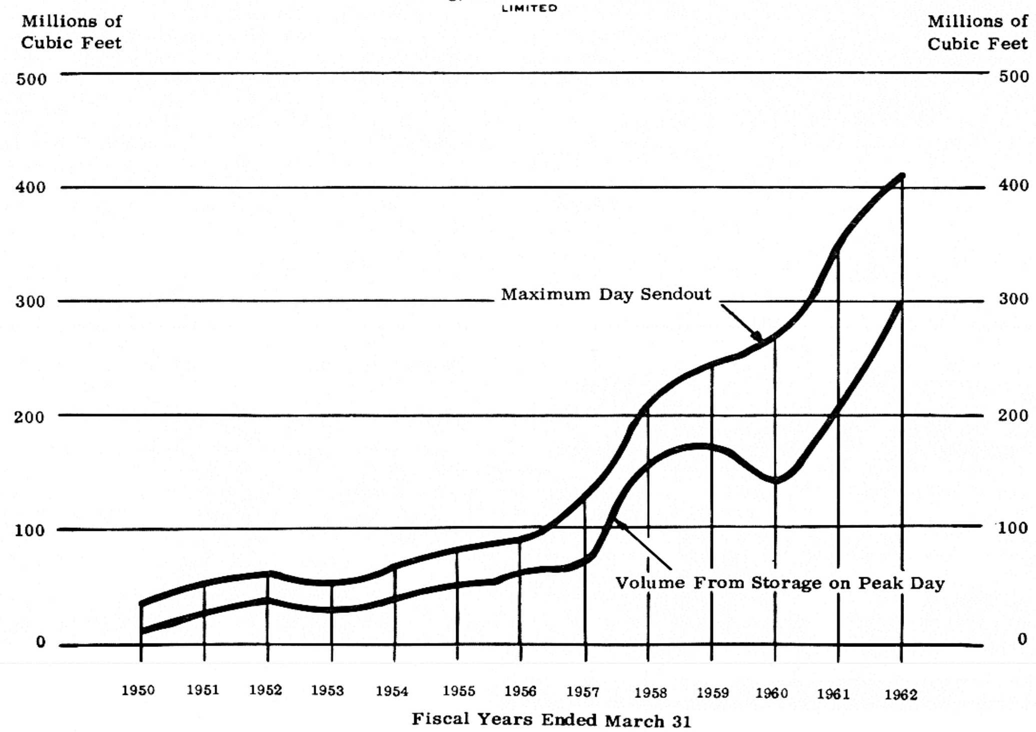


Fig. 15 Typical Wellhead Completion, Without Tubing.

USE OF STORED GAS IN MEETING PEAK LOADS 1950-1962

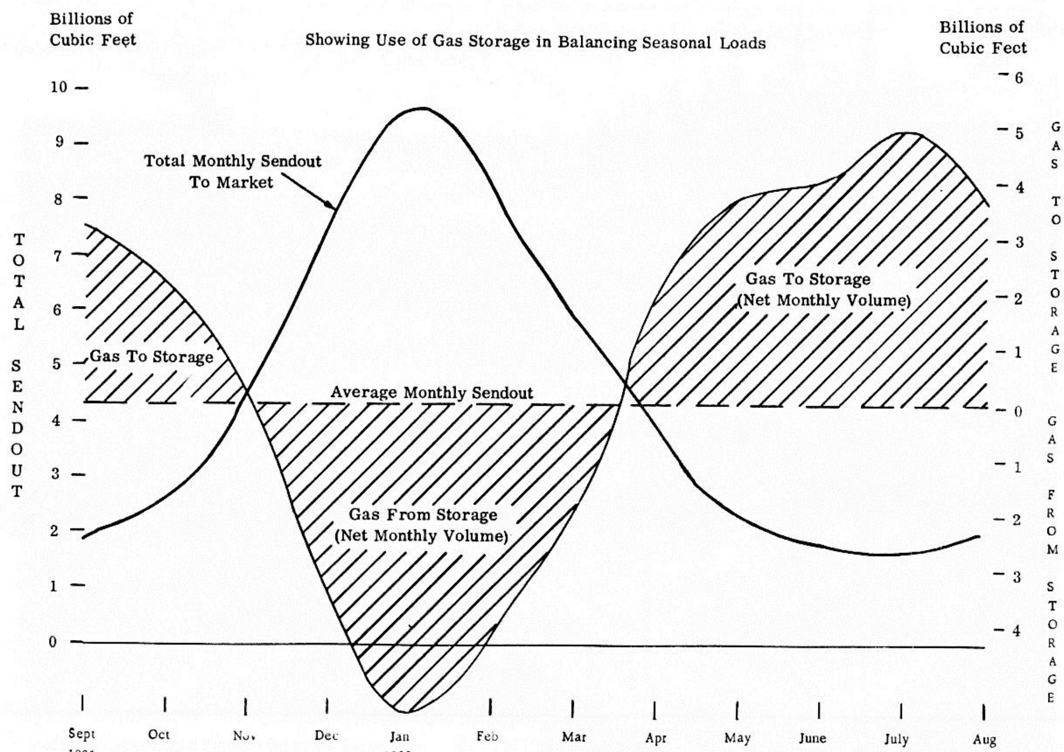
UNION GAS COMPANY OF CANADA, LIMITED



MARKET REQUIREMENTS AND STORAGE OPERATION - 1961-62

UNION GAS COMPANY OF CANADA, LIMITED

Showing Use of Gas Storage in Balancing Seasonal Loads



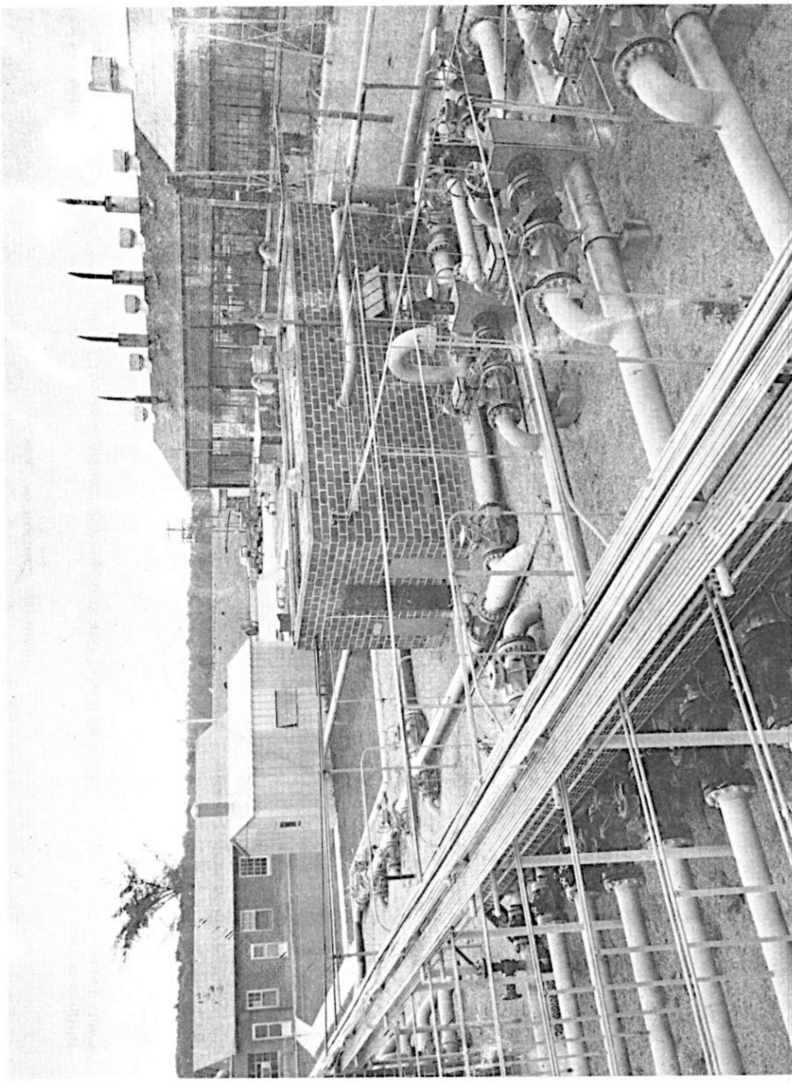


Fig. 18 View of Part of Dawn Compressor Station and Gas Dispatching Control Centre.

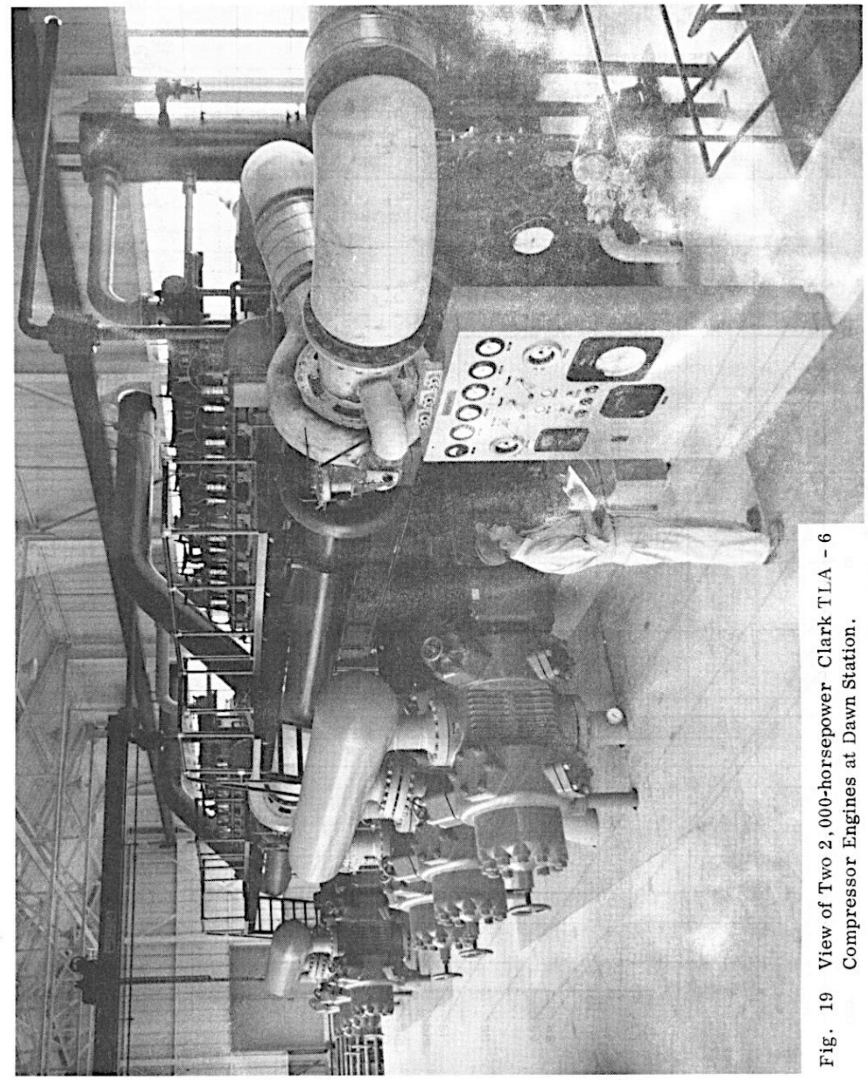
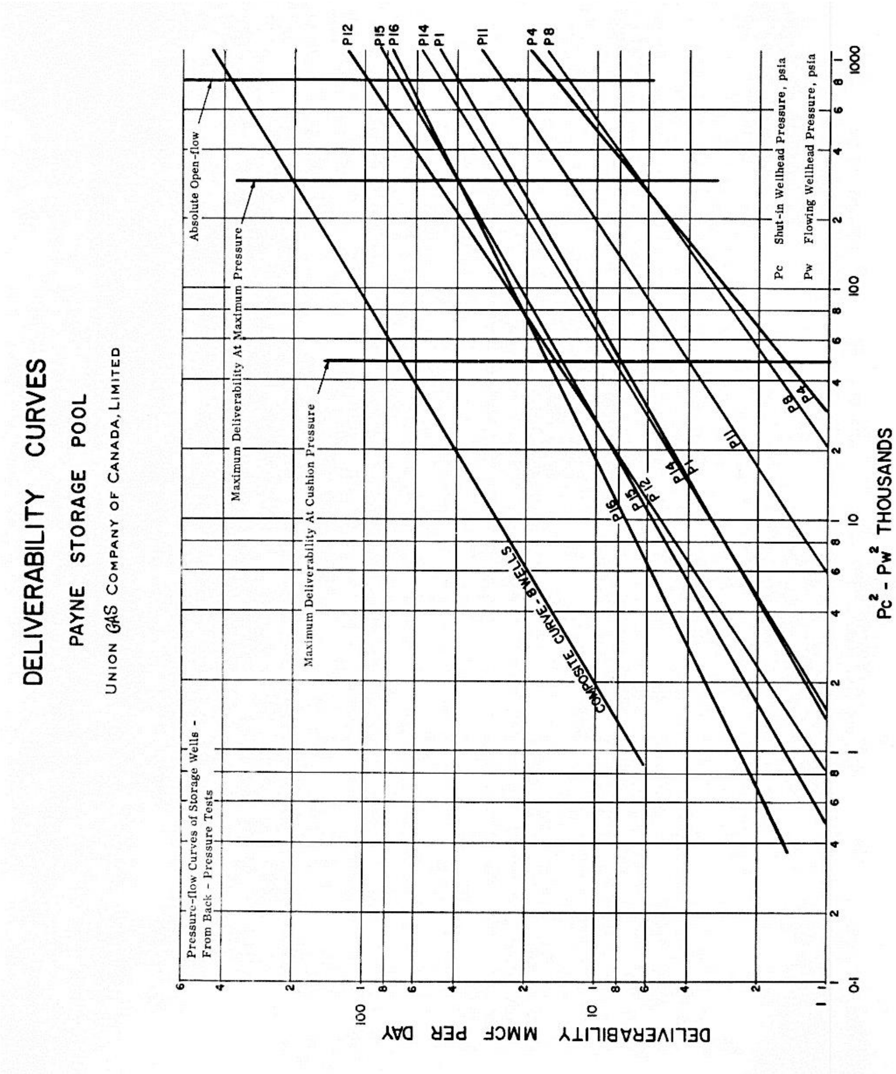
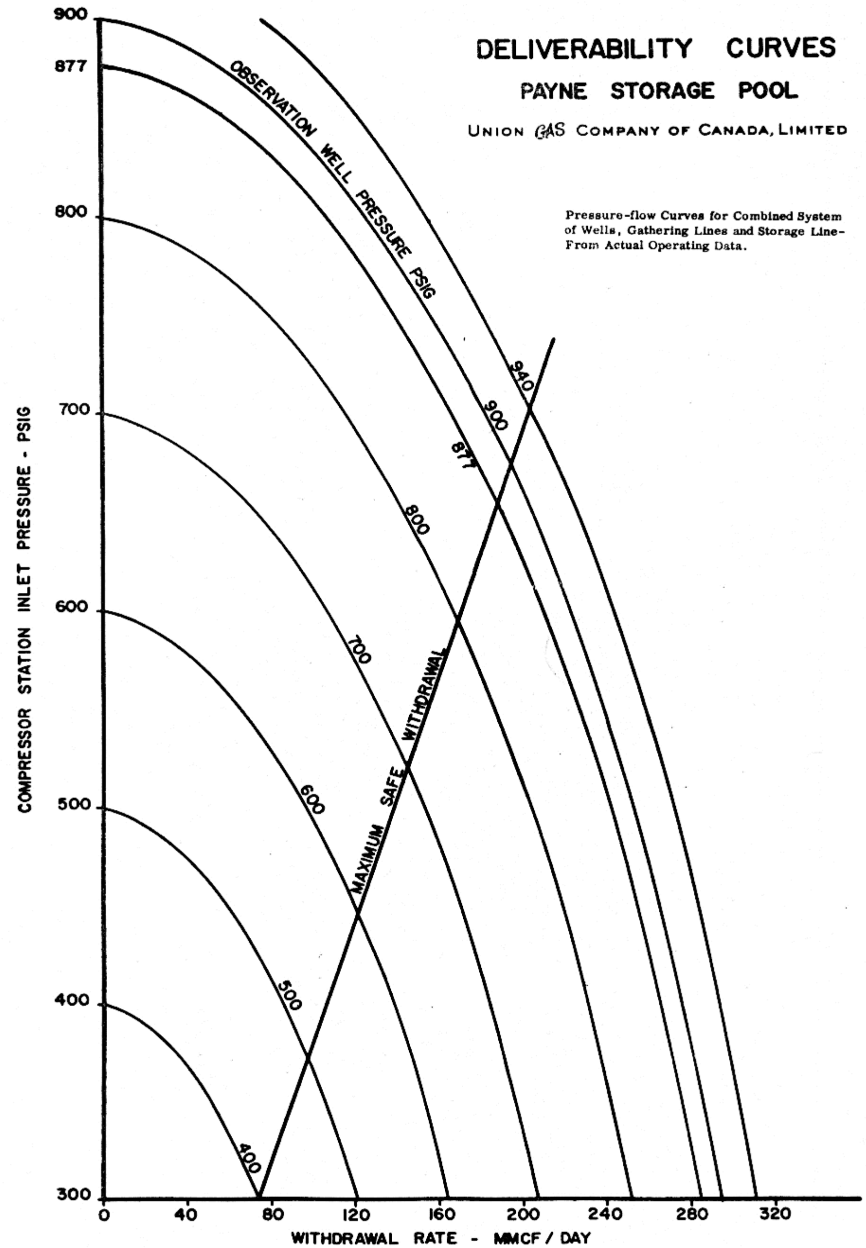


Fig. 19 View of Two 2,000-horsepower Clark TLA - 6 Compressor Engines at Dawn Station.


DELIVERABILITY CURVES
PAYNE STORAGE POOL
UNION GAS COMPANY OF CANADA, LIMITED
Absolute Open-flow
Maximum Deliverability At Maximum Pressure
Maximum Deliverability At Cushion Pressure
Pressure-flow Curves of Storage Wells - From Back - Pressure Tests
Pc Shut-in Wellhead Pressure, psia
Pw Flowing Wellhead Pressure, psia
COMPOSITE CURVE - 8 WELLS
P12
P15
P16
P14
P1
P11
P4
P8
DELIVERABILITY MMCF PER DAY
Pc² - Pw² THOUSANDS


DELIVERABILITY CURVES
PAYNE STORAGE POOL
UNION GAS COMPANY OF CANADA, LIMITED
Pressure-flow Curves for Combined System of Wells, Gathering Lines and Storage Line-From Actual Operating Data.
OBSERVATION WELL PRESSURE PSIG
MAXIMUM SAFE WITHDRAWAL
940
900
877
800
700
600
500
400
COMPRESSOR STATION INLET PRESSURE - PSIG
WITHDRAWAL RATE - MMCF / DAY
0
40
80
120
160
200
240
280
320
300

Archived Technical Papers for Block 2: Environment and Risk Management

Featured Article: O'Shea, K., Fairbank, C., & O'Shea, H. (1996). Environmental Impact of Historical Oilfield Properties and Practices, Ontario. *Ontario Petroleum Institute Gold Volumes, 35*(12).

Additional References

Barrett, M. (2007). Energy, Education: The Key to Our Future. *Ontario Petroleum Institute Gold Volumes, 46*(13).

McGovern, S. (1995). Risk Management. *Ontario Petroleum Institute Gold Volumes, 34*(3).

O'Shea, K. (1993). Environmental Regulation of the Oil and Gas Industry in Ontario: Taming the Beast. *Ontario Petroleum Institute Gold Volumes, 32*(2).

Shanoff, T. (2011). Spill Response at Oil and Gas Sites in the Information Age – Challenges and Successes. *Ontario Petroleum Institute Gold Volumes, 50*(17).

Tasker, C. (2012). Source Protection Planning in the Thames-Sydenham and region**.** *Ontario Petroleum Institute Gold Volumes, 51*(13).

TECHNICAL PAPER NUMBER TWELVE

"ENVIRONMENTAL IMPACT OF HISTORICAL OILFIELD PROPERTIES AND PRACTICES, ONTARIO"

by

Kerry O'Shea
AGRA Earth & Environmental
Waterloo, Ontario

Environmental Impact of Historical oilfield Properties and Practices, Ontario

by

Kerry O'Shea, Charles Fairbank and Hank O'Shea

The oil industry as we know it today has undergone many changes in its 140 year history and continues to be an evolving, changing and growing industry. From the initial exploitation of the gum beds of Enniskillen in the early 1850s for asphalt, to the current exploration and development of oil and gas off the east coast of Canada, the oil industry has sparked many technological and sociological changes in western society. The development of oil and gas as cheap, clean sources of energy has been the fuel that has powered the technological society in which we live. Over the years, as society has grown away from understanding the basis from which it has grown, the oil and gas industry has often been given the guise of villain, treated with contempt, viewed with suspicion and considered to be a contributor to the destruction of our natural environment.

In Ontario, where the first commercial well in North America was completed near Oil Springs in 1857, the oil industry has gone through the original booms, peaked and settled into maturity. Additional discoveries continue to be made in Ontario, with strong production continuing, but to most people in Ontario, we have no primary oil and gas industry. With the large manufacturing base that is present in Ontario, the number of people who derive their income directly from the primary oil and gas industry is small, and continues to shrink. For the majority of the population, the oil industry in Ontario consists of the big refineries in Sarnia, and the retail gasoline outlets found ubiquitously throughout the world.

Given the lack of knowledge by the general public of the primary industry, and the perception that oil is big and dirty, the environmental perception of the oil and gas industry is generally negative; Gas stations leak, and refineries smell - therefore all oil and gas industries are dirty. Unfortunately, the primary producers are tarred with the same brush, and all oil and gas properties and developments, by-products and wastes become environmentally suspect in the public's eye.

The media of this province, and throughout the world are quick to sell negative news, and compound the distrust and uncertainty associated with the environment in the eyes of the public. It is a strong combination - the press and the public, and when politicians are tossed into the mix, the results can be explosive!! (Some would suggest that the addition of environmental consultants to the mix can lead to even greater outpourings of grief)!!

In 1996, our society is undergoing dramatic change, perhaps even fundamental in its scope and breadth. As part of this change, governments are reducing the role they play in regulating and directing our industry. Many will say that the change is long overdue, but many will also say that without the strong hand of government wielding an environmental whip, that the destruction of our environment will proceed at a great rate. Some suggest that we may now be creating the issues and problems that will need to be solved in the future.

However, within the oil fields of Petrolia and Oil Springs, we have a 140 year history of changing industry practices, approaches and public perceptions to use as a backdrop to measure some of today's environmental concerns against - a backdrop that includes over 100 years of continuous activity before the passing of the Petroleum Resources Act (1964), and over 120 years of continuous activity before Love Canal. In the environmental field we generally can trace the strong development of fundamental environmentalism to the Love Canal issue of Niagara Falls New York, circa 1980.

To illustrate the early industry, we have looked at a series of publications that provide written, eye witness accounts of the early developments in Oil Springs, including the gushers of Shaw, Black and Mathiesons's, McLean et al and five or six others. The London Free Press reported in 1862 that about 100,000 barrels were lost, and that oil was four inches thick on the creek from Shaw's well alone before it was brought under control. The "loss of 100,000 barrels of oil", most into the nearby Black Creek and ultimately into Lake St. Clair, in 1862 constituted an amazing story - with not a single mention of the environmental concerns. Contrast the reaction of 1862 with the reaction of the public to the Exxon Valdez running aground in Alaska a few years ago. (We'll come back to this later).

Other reports of the 1860s describe the drillers working in mud/oil up to their knees, with the ground being black for acres. And still the gushers came in, adding more oil to the ground. Today, when we look for the legacy of those original oil spills, we cannot generally find many traces. The old spills provide one example of environmental impact that today is treated far differently then in the 1860's.

In today's political and social climate, with greater population pressures and instant media communication, spills are reported rapidly around the world - which forces a rapid, and often deleterious response by the authorities/companies involved. For example, after the Exxon Valdez spilled oil onto the Alaska shoreline, an army of environmental cleanup experts, scientists and lawyers descended into Prince William Sound. The cleanup included blasting the oil soaked beaches with high pressure steam to remove every last vestige of the oil. Interestingly, in an October 1996 Scientific American article, it was reported that one study of the beaches in the Sound showed that the beaches that were steam cleaned were in poorer shape then the beaches that were left alone - this is a case of the cure being worse then the disease.

The following series of pictures were taken by Charlie Fairbanks along Black Creek a few years ago. These pictures are from the area that is just downstream of the Shaw Gusher and the Black and Mathiesons Gusher. You will note that the creek looks quite healthy - no sign of the oil impact.

But does this picture of natural health reflect the true impact - or do we have a hidden menace underlying the green green grass of home?

In 1988 the Ontario Ministry of the Environment funded a detailed study of the environmental condition of the Petrolia area. The study resulted in the publication of a several volume work, which included assessments of the environmental condition and included remedial recommendations. The reports are still in circulation and are often referred to by Government agencies when discussing the Petrolia area.

In the fall of 1988 the London Free Press issued a brief news article on the reports - and focussed on the 600 million dollar cleanup recommended for Petrolia and historic oil field properties. In hindsight, the results of the study really indicate that there is lots of potential, but little real work to be done. This is somewhat different from the story as presented by the press and interpreted by many many people. By way of emphasizing this point, we wish to paraphrase and/or quote out of the hydrogeological portion of this study. The report looked at potential impacts to ground water from in-ground tanks and from injection/brine disposal wells and reached the following conclusions

- For the buried tanks, the potential zone of impact is related to surface flow via overflow, and transport of potentially contaminated ground water to the ditches. The shallow ground water in the upper weathered zone may be contaminated and may discharge to drainage ditches, but the loading would be small due to the low flow rates in the clay till.

- For the potential of flow from the tanks (i.e. leakage) from the tanks below the weathered zone, resulting in impact to the freshwater aquifer at the top of the bedrock, the conclusion that was reached that advective transport of the contaminated ground water (large scale flow) was unlikely and furthermore, - and this is a direct quote - "It is unlikely, however, that (diffusive) contaminant transport (downward) would ever cause a measurable impact on the aquifer, particularly from a single tank".

The tanks being discussed are indeed the hand dug, clay puddled, oak staved tanks with clay bottoms found in many locations - some of which are decades old. Considering that the longevity of steel tanks is on the order of ten to fifteen years, the oak tanks should perhaps be the wave of the future - at least where there is a thick clay sequence to provide secondary containment!

- For the disposal and brine injection wells, it was concluded that the potential for impact to the local aquifer was unlikely, and that the influence would be very localized, to within tens of meters from the injection well.

Soil contaminants were indeed identified in the Petrolia area, and include petroleum hydrocarbons, tank bottoms and the spillage of recent operations. However, it was concluded that much of the contamination was not toxic. Looking at the results today, using the current guidelines as released by the MOEE in June, 1996 for contaminated sites, it is hard to find a significant environmental liability related to the old properties. Of course we are somewhat selective and have not included the old refineries.

Recently AGRA Earth and Environmental Limited (AEE) completed an assessment for a property in Petrolia, along Tank Street. During the course of the assessment AEE located a well - cased with wood, and three small tanks. The abandonment of the well is straight forward and was not considered to be a significant issue. The three tanks contained some petroleum contaminants - but only in the fill, not in the native soils. AEE's conclusion - that the areas of the former tanks should be cleaned out and replaced with engineered fill - which was a geotechnical consideration - not an environmental issue. The impacted soil was to be used for on-site landscaping.

Why then the big headline in the London Free Press in 1988 and the resulting high level of regulatory concern directed at the historic properties??

We must examine the time at which the Free Pess report was issued - in 1988, almost at the height of the environmental fundamentalism that was rising in our society. We are still living with the legacy of that fundamentalism, and while there are many reasons for environmental concern in the oil and gas industry in Ontario, the experience at Petrloia and Oil Springs has shown that in parts of Ontario where the industry has been operating for over 120 years, and that after an intial period of high impacts, has settled into low production, that the impact of the initial spills has faded without the intervention of government or science, showing that the natural environment can heal itself.

To conclude, there are three points that we would like to emphasize.

First, the geology of the Petrolia and Oil Springs area, which lead to the development of the oil industry, has also acted to protect the environment. The thick sequence of relatively impermeable clay overlying the fresh water aquifer has served to shield the aquifer from surficial impacts, and has kept the surficial impacts very close to the source - that is there is no widespread impact from a single source. The tight clays have also kept the in-ground oak tanks from causing impacts, and appears to have acted as a secondary containment seal for the tanks, which is something that cannot be achieved with above ground tanks very easily.

Second - the low volumes of production and the extended time frame of production dictated by the oil bearing formations has lead to the longevity of the oil industry in the Oil Springs and Petrolia areas. The low production volumes has also kept the industry working with small scale operations, which in turn have reduced the potential for large scale environmental impacts. The initial gushers of the 1860s are the exception, but again the long time frame since the initial spills has allowed nature to heal itself.

The third point is that there is a large amount of resiliency within the natural environment that adapts to change, and can in effect remediate the contamination. Off course the remediation via natural means requires time, low levels of impact and a contaminant that is degradable - which is what oil is. The experience of the Exxon Valdez has shown that even in areas where there is tremendous impact from spilled oil, that left to itself, the natural microbial community will remediate the oil, changing the nature of the environment perhaps, but not destroying it completely.

From these three points we would like to make one conclusion, and also issue a warning. The conclusion is that many of the environmental charges that have been levelled against the industry, and many of the regulations and acts set up to control the industry are a reaction to specific events that are viewed from the perspective of a limited time frame - in short , a reaction to an issue (which may only be perceived as an issue), without the benefit of a specific and sound assessment of the technical data. Reality suggests that many of our environmental issues relate to potentials as opposed to hard fact.

Archived Technical Papers for Block 3: Hydrocarbons

Featured Article: Cater, T.R., & Castillo, A.C. (2003). 3D Mapping in the Subsurface of Southern Ontario Using GIS and Digital Petroleum Well Data. *Ontario Petroleum Institute Gold Volumes, 42*(18).

Additional References

Carter, T.R., Trevail, R.A., & Easton, R.M. (1993). Oil and Gas Accumulations and Basement Structures in Southern Ontario. *Ontario Petroleum Institute Gold Volumes, 32*(9).

Elliot, C.B. (1991). Geographic Information Systems and Land Management in the Ontario Oil Patch. *Ontario Petroleum Institute Gold Volumes, 30*(6).

Tillman, N., Sims, J., Vehrs, T. (1986). Generating and Evaluating Prospects with Play- Specific Geochemical Techniques. *Ontario Petroleum Institute Gold Volumes, 25*(9).

TECHNICAL PAPER

NUMBER EIGHTEEN

"3D MAPPING IN THE SUBSURFACE OF SOUTHERN ONTARIO USING GIS AND DIGITAL PETROLEUM WELL DATA"

By

Terry Carter
Ministry of Natural Resources
London, Ontario

3D MAPPING IN THE SUBSURFACE OF SOUTHERN ONTARIO USING GIS AND DIGITAL PETROLEUM WELL DATA

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ABSTRACT

The Petroleum Resources Centre of the Ontario Ministry of Natural Resources (MNR) collects and manages a large quantity of subsurface resource and geological data acquired from the drilling of petroleum wells by industry clients. Public access to this data is through the Oil, Gas and Salt Resources Library and includes drill cuttings and drill core, well location, well status, operator identification, drilling dates and depths, well construction, geological formation top depths and elevations, oil/gas/water intervals, geophysical well logs, core analyses, analyses of oil, gas and water samples, subsurface pressures and production volumes.

The MNR and the Library are in the fourth year of an ongoing project to digitize Ontario's petroleum well data using funding provided by the Oil, Gas and Salt Resources Trust. Digital data derived from the well records and samples are maintained in an Oracle relational database known as the Ontario Petroleum Data System (OPDS). The Centre has recently developed a Geographic Information System (GIS) application using Arcview 3.2 for general viewing and querying of this data as well as a specialized application for subsurface geological mapping. A petroleum well theme is generated by a dynamic link to the Oracle data tables in OPDS. Elevation data for the tops of subsurface bedrock formations is extracted from the Oracle data tables using the "PetroGIS" application and can then be gridded and contoured using specialized software such as Surfer. The results can be displayed as a new data theme in the GIS. Three-dimensional maps created from the gridded data are particularly useful for visualization and mapping of subsurface structures such as faults, reefs, salt dissolution and collapse features, regional dip, structural closures, bedrock topography and more.

Basic well data including corrected geographic co-ordinates are available at www.ogsrlibrary.com and clients are able to purchase data on subsurface geological formation top picks, oil, gas and water intervals and enhanced well data. Access to MNR digital base maps and the PetroGIS application is free to corporate members of the Library under the terms of a data sharing agreement with the Ministry of Natural Resources.

INTRODUCTION

The Ontario Ministry of Natural Resources has maintained a digital database of petroleum well data since 1964 with a long history of modifications and updates to accommodate advances in computer hardware and database software. In early 2000 the Ontario Oil, Gas & Salt Resources Corporation (OOGSRC) and the MNR initiated a partnership using funds of the Oil, Gas and Salt Resources Trust (Trust) to further develop and populate this database (Carter, 2001), improve public access and add GIS capability. This report summarises the current status of these efforts and provides examples of the new subsurface mapping capabilities.

Most well data is stored in linked data tables on the Ontario Petroleum Data System, a custom Oracle relational database system owned and operated by the MNR. GIS capability is provided by a custom Arcview 3.2 application developed by the MNR and known as PetroGIS. PetroGIS links the Oracle data tables to MNR digital base maps. Data editing is funded by the Trust using staff of the Oil, Gas and Salt

Resources Library (Library). By the end of 2003 the Trust had contributed nearly $300,000 to expedite entry and editing of spatial and attribute data into OPDS. Records are available for over 20,000 wells and includes data on well location, ground elevation, well status, operator identification, drilling dates and depths, well construction, geological formation top depths and elevations, oil/gas/water intervals, geophysical well logs, core analyses, analyses of oil, gas and water samples, subsurface pressures and production volumes.

PetroGIS provides an intuitive, map-based interface for general viewing and querying of data for petroleum wells. Of particular interest to geologists is the capability to select and export formation top picks for creation of subsurface structure top and isopach maps as well as 3D mesh and surface maps. Three-dimensional maps created from the gridded data are particularly useful for visualization, interpretation and mapping of subsurface structures such as faults, reefs, salt dissolution and collapse features, regional dip, structural closures, bedrock topography and more. These maps can then be used as tools for interpretation of the location and boundaries of oil and gas reservoirs, pathways for groundwater movement, delineation of bedrock resources, etc.

DATA COLLECTION AND STANDARDS

Collection and management of subsurface geological data from petroleum wells drilled in Ontario began in the late 1800's when the Borings Division of the Geological Survey of Canada solicited voluntary submissions of drill cuttings and cores from oil and gas wells drilled in Ontario and other parts of the country. This informal collection evolved into the establishment of a core and cuttings sample processing, storage and study facility in Ottawa. In 1971 Ontario core, cuttings and well records were shipped to the new provincial Petroleum Resources Laboratory, now known as the Oil, Gas and Salt Resources Library, located in London, Ontario.

Systematic collection and recording of well data by the Ontario government began in 1915 when the Ontario Bureau of Mines included a summary of well drilling activity in its annual report (Beards, 1967). In 1922 R. B. Harkness, newly appointed Commissioner of Natural Gas, made this an annual feature. Today all companies that drill or operate petroleum wells in Ontario are required to licence their wells under the provincial Oil, Gas and Salt Resources Act and its regulations. Data collection and reporting requirements are established by the Provincial Operating Standards and core, cuttings and other data are stored at the Library for public access.

The well records and core and cuttings collection was moved to the Library in 1987. The Library maintains files on more than 20,000 wells, houses drill cuttings samples for over 13,000 wells, cores for over 1,000 wells and has an extensive collection of books, government reports and maps, journals, reprints and published and unpublished documents and reports. Hard-copy geophysical logs are available for approximately 4,000 wells. Areas covered by this wealth of data include those portions of Ontario underlain by stratified rocks of Paleozoic or younger age in southern Ontario, the Ottawa area, and the James Bay Lowlands in northern Ontario.

Well Location Standards

When new wells are licensed in Ontario the operator of the well is required to provide a location plan which describes the exact location of the well in relation to the nearest corner of the township lot within which it is located and the ground elevation of the well site above mean sea level. Measurements are required to be accurate to the nearest $1/10^{th}$ of a metre. Since 1997, well operators have also been required to provide geographic coordinates (latitude and longitude) of the well location, measured and reported to the nearest $1/100^{th}$ of a second. For wells drilled prior to 1997 that have no geographic coordinates but with known locations relative to township lot lines, a customized tool in PetroGIS is used by MNR or Library staff to derive latitude and longitude co-ordinates. Co-ordinates determined in this

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way have an accuracy of 1/10 of a second. Well geographic locations are also acquired using a Trimble Geo Explorer III GPS instrument. Locations acquired in this way have an accuracy of 3 to 5 m.

All geographic co-ordinates are recorded in the NAD83 co-ordinate system and are recorded in the Ministry's well database in decimal degrees to eight decimal places.

Geological Formation Tops

During the drilling of a new well the operator is required to collect cuttings samples of bedrock from the entire length of the well bore and deliver these samples to the OGSR Library for processing and cataloguing for storage. Drill core recovered from a well is required to be submitted to the Library within one year after the completion of drilling. Well operators are also required to submit copies of all drilling reports, geophysical logs, analyses, tests, etc to the Ministry. Copies of all reports, analyses, etc are available at the Library for public study after the expiry of a confidentiality period, which is one year for exploratory wells and 30 days for all other wells.

The well operator records formation top depths on a standardized drilling and completion report that is submitted to the Ministry. These data are recorded in the Ministry's Oracle database and subsea elevations are calculated for the formation tops using the calculated rig floor elevation data. Accuracy of this data varies from well to well depending on accuracy of the rig floor elevation, quality of samples, the skill of the geologist, and availability of geophysical logs.

Formation tops for most wells have also been determined by Ministry geologists or geologists of the Geological Survey of Canada, principally Bruce Sanford, using standards established by Beards (1967). Standardized stratigraphic nomenclature used by MNR geological staff is based on Beards (1967), Sanford and Quillian (1959), Sanford (1961, 1969), Uyeno et al (1982), Winder and Sanford (1972), and Johnson et al (1992).

THE ONTARIO PETROLEUM DATA SYSTEM

The history of development of Ontario's petroleum well data system is summarised in Carter (2001). The current version of OPDS is a client server application consisting of an Oracle 8.0.5.1 relational database and a related custom software application written in Powerbuilder 6.5. The software application is loaded on local workstations running Windows XP.

OPDS is used for entry, editing, viewing and querying data and for producing reports and approvals including licences for petroleum wells. The stored data includes well location, well status, operator, drilling dates and depths, geological formation tops, well construction, oil/gas/water intervals, logging intervals, cored intervals, drill sample disposition, etc. for over 20,000 wells.

Data Entry, Editing, and Maintenance

Data entry, editing and maintenance for newly licensed and currently active wells is the responsibility of staff of the Petroleum Resources Centre. Editing and updating of data for previously drilled wells is the responsibility of staff of the Oil, Gas and Salt Resources Library. Data entry utilizes custom data entry screens that are nearly identical to the application forms and reports submitted by industry under the requirements of the Oil, Gas and Salt Resources Act and its regulations and standards. Look-up tables and validation constraints are used to filter data entry to maintain data integrity (see Carter, 2001). This project is scheduled to be completed in 2005.

DATA ACCESS

The Library is the principal public source of Ontario well data. Clients may visit the Library to study drill core and cuttings, view, interpret and copy geophysical well logs, search well records, use the reference library, etc. Modest fees are charged for use of the facilities.

Basic well data including corrected geographic co-ordinates are posted for free download from the OGSR Library website at www.ogsrlibrary.com as data editing is completed. Information available includes well name, well licence number, location, geographic co-ordinates, operator, well type and mode, well classification, geological target, total depth, licence issue date, drill start date, drilling td date, plugging date, drill core number, and pool name. Access to the database using PetroGIS is now available on a workstation in the Library connected to the MNR network. Alternatively, Library staff can be contracted to perform custom queries for clients and provide the results as maps, spreadsheets or database files. In the summer of 2003 the Library announced the release of data tables of geological formation tops. For information on data access clients can visit the website of the OGSR Library at www.ogsrlibrary.com.

Digital Base Maps of Ontario

Digital base maps for Ontario are stored in a general purpose data system known as the Natural Resources Values and Information System (NRVIS), developed by the Science and Information Resources Division of the Ministry of Natural Resources (Carter, 2001). Base data features such as roads, streams, water bodies, township lots, etc. are derived from the Ontario Base Maps which have been mosaiced to form a seamless coverage of the entire province to approximately 51^{0} latitude. Access to the digital map data is currently provided through a data sharing agreement between the Ontario Oil, Gas and Salt Resources Corporation and the MNR. Access privileges are extended to all corporate members of the Library.

PetroGIS

GIS technical staff of the Ministry have designed and written a GIS application in Arcview 3.2 using the Avenue scripting language, which links some of the OPDS data tables to the Ministry's digital base maps of Ontario. Retrieval of data from the Oracle tables is performed by using PetroGIS to establish a connection to the Oracle database through an Open Database Connectivity (ODBC) connection and downloading the data to the local hard drive as a dBase file (.dbf). The .dbf file constitutes a "snapshot" of the data stored in OPDS at the time of the download and can be updated at any time by the user. Data that can be queried and viewed in the current application include well licence number, well name, operator, well status, initial classification, target, total depth, formation at TD, county, township, lot, concession, latitude and longitude, pool name, primary producing formation, initial oil and gas rates, depths of oil, gas and water-bearing intervals, initial pressure, dates, and sample and core information. Well locations are modeled as points, plotted using the geographic coordinates recorded in OPDS. Base map features include counties, townships, roads, water bodies, cities, lots, concessions, railroads, buildings, etc. (Fig.1).

A geological module for extraction of depths and elevations of geological formation tops became functional in the fall of 2002 and can be used to create contour maps and 3D surface and mesh maps of subsurface bedrock formations. The module is essentially a specialized query using a customized button. The user selects the area and wells to be included in the map, the formation top to be mapped and chooses between MNR and operator formation top picks. The user also has the option to save well location coordinates as either latitude and longitude in decimal degrees or as UTM coordinates. After execution of the query the resulting table includes formation top elevation data for all the selected wells (Z value) and location coordinates (X and Y values). This table may be exported as a dBase file, an ArcInfo table or as a comma-delimited text file (Fig.2).

CARTER and CASTILLO

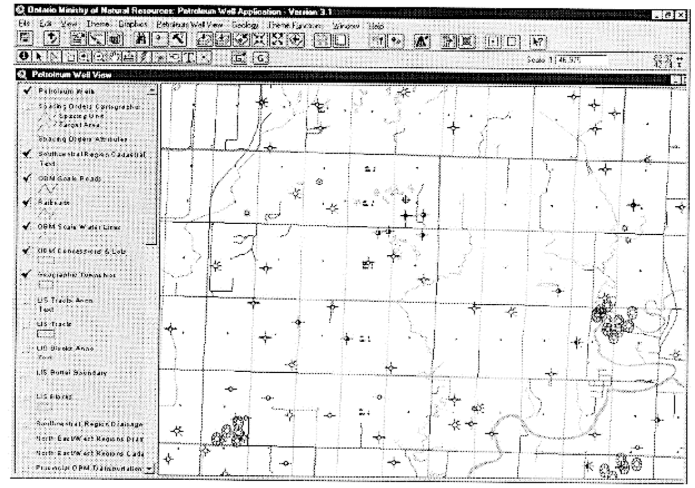
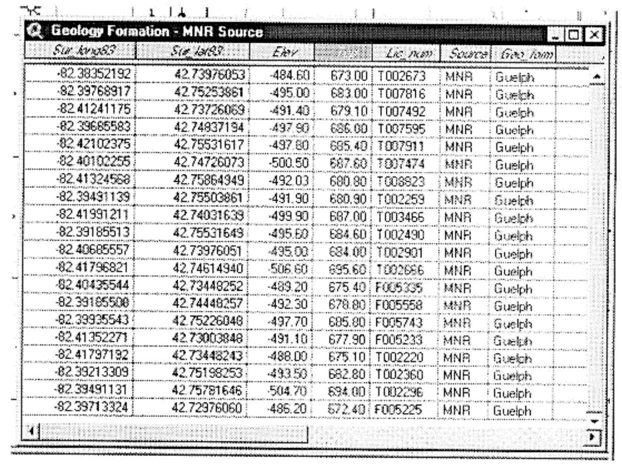


Figure 1: PetroGIS screenshot showing petroleum well locations relative to township lot lines, roads, and water bodies. Well symbols represent different well types and status such as natural gas wells, oil wells, dry holes, natural gas storage, etc



Geology Formation - MNR Source

Sur_long83	Sur_lat83	Elev		Lic_num	Source	Geo_form
-82.38352192	42.73976053	-484.60	673.00	T002673	MNR	Guelph
-82.39768917	42.75253861	-495.00	683.00	T007816	MNR	Guelph
-82.41241175	42.73726069	-491.40	679.10	T007492	MNR	Guelph
-82.39685583	42.74837194	-497.90	686.00	T007595	MNR	Guelph
-82.42102375	42.75531617	-497.80	685.40	T007911	MNR	Guelph
-82.40102255	42.74726073	-500.50	687.60	T007474	MNR	Guelph
-82.41324568	42.75864949	-492.03	680.80	T008823	MNR	Guelph
-82.39491139	42.75503861	-491.90	680.90	T002259	MNR	Guelph
-82.41991211	42.74031639	-499.90	687.00	T003466	MNR	Guelph
-82.39185513	42.75531649	-495.60	684.60	T002490	MNR	Guelph
-82.40685557	42.73976051	-495.00	684.00	T002901	MNR	Guelph
-82.41796821	42.74614940	-506.60	695.60	T002686	MNR	Guelph
-82.40435544	42.73448252	-489.20	675.40	F005335	MNR	Guelph
-82.39185508	42.74448257	-492.30	678.80	F005558	MNR	Guelph
-82.39935543	42.75226048	-497.70	685.80	F005743	MNR	Guelph
-82.41352271	42.73003848	-491.10	677.90	F005233	MNR	Guelph
-82.41797192	42.73448243	-488.00	675.10	T002220	MNR	Guelph
-82.39213309	42.75198253	-493.50	682.80	T002360	MNR	Guelph
-82.39491131	42.75781646	-504.70	694.00	T002296	MNR	Guelph
-82.39713324	42.72976060	-486.20	672.40	F005225	MNR	Guelph

Figure 2: PetroGIS screenshot with inset showing formation top data for selected wells ready for export as a Dbase data file. The first, second and third columns comprise the X (longitude), Y (latitude) and Z (formation top elevation) values for gridding and contouring. Also shown is the formation top depth in metres (Top), the well licence number (Lic_num), source of geological data (Source). Geo_form indicates that the data is for the Guelph Formation.

SUBSURFACE MAPPING METHOD

In the present study all contour and 3-dimensional maps have been created using Surfer 8 gridding, contouring and 3D surface mapping software (Golden Software, 2002). The Dbase files exported from OPDS are imported into Microsoft Excel and saved as an Excel worksheet to create a format that can be read by Surfer. An XYZ data file is then created where each row in the data file is a separate record representing a well and the X, Y and Z values are the columns. In this study the X and Y coordinates are the longitude and latitude values, respectively for the well location, and the Z values are the elevations at which the well encountered the tops of each geological formation.

All maps created using Surfer first require the generation of a regular, rectangular array of values using a gridding algorithm. Gridding calculates values by interpolating the elevation values of geological surfaces at individual wells and assigning it to a grid node. These gridded values are then contoured to produce a map.

Gridding algorithms available for use in Surfer include kriging, nearest neighbour, inverse distance to a power, minimum curvature, modified Shepard's method, natural neighbour, polynomial regression, radial basis function, triangulation, moving average, data metrics and local polynomial (Golden Software, 2002). These algorithms were evaluated by the authors through construction of contour maps of the gridded surfaces of selected strata and comparing the results to earlier hand-contoured maps (Carter, 1991). Point kriging using the default linear variogram produced a good match for the surfaces tested and was used to construct all the maps in this study. Because of the good match obtained with the linear variogram, the large number of surfaces mapped and the limited scope of the present study the authors did not evaluate the suitability of other possible kriging variograms.

Contour maps and 3D maps were created from the gridded data. Isopach maps were generated using a grid math algorithm to subtract the grid values for the lower surface of a formation from the upper surface. The surface of the immediately underlying formation is used to define the lower surface of a formation. The resulting grid file represents the thickness of the formation, which can then be contoured or mapped as a 3-dimensional volume.

Data Integrity

Failure to identify and correct or eliminate incorrect data is the most common source of error in subsurface mapping. Errors which affest geological mapping are inaccurate well location coordinates, ground surface elevation, calculated rig floor elevations and incorrect or inconsistent formation top depths. Errors are usually manifested as single well anomalies on contour or 3D maps prepared from the data. Anomalous values must be checked and verified, corrected if possible, or eliminated from the data set.

Formation top data recorded in OPDS is acquired from two sources; picks reported by the operator of the well and recorded on their drilling and completion report filed with the Ministry or picks made by geological staff employed by or contracted to the Ministry. Picks submitted by the well operator have been made by a large number of different individuals with widely varying levels of skill, knowledge and experience. Ministry picks have been made by a much smaller number of individuals under the supervision or direction of an experienced geologist in accordance with the standards established by Beards (1967). The user is able to choose which source of formation top data to use for mapping.

SUBSURFACE GEOLOGICAL MAPPING EXAMPLES

The authors tested the efficacy of the new mapping tools by constructing contour and 3D maps of selected subsurface Silurian strata beneath Lambton County and the geographic township of Sombra in southern Ontario. More than 6000 petroleum wells have been drilled in Lambton County since 1858 (Fig 3).

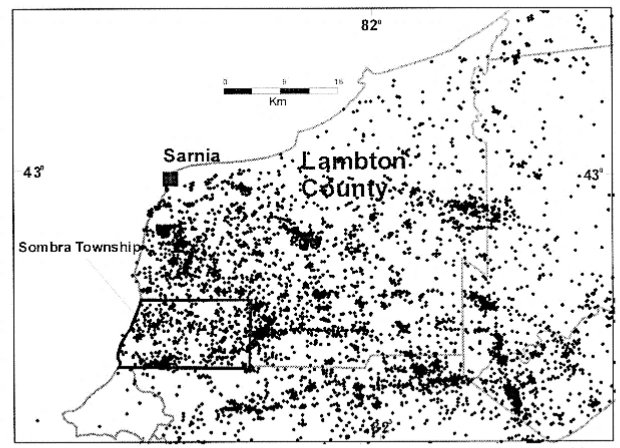


Figure 3: Map showing distribution of petroleum wells in Lambton County and Sombra Township.

In the following examples all formation tops were picked by geological staff trained and supervised by the first author (Carter, 1991) and subsequently recorded in OPDS. 3D and contour maps were constructed using these formation tops. Obviously anomalous values were corrected or deleted from the data set.

The figures that follow are chosen primarily to illustrate the sequence of deposition of sedimentary strata in Sombra Township and/or Lambton County from the top of the middle Silurian Rochester Formation to the top of the upper Silurian Salina Group (Fig. 4) and the effects of faulting, reef development and the deposition and subsequent local dissolution of salt on the structure and thickness of these strata.

Unless indicated otherwise all 3D maps in this report are orthographic projections viewed from southwest to northeast at a 30-degree tilt and a sun angle of 45 degrees. The original colour legend has been converted to greyscale for reproduction. All images were created in Surfer 8, exported as .jpg files and imported into CorelDraw 9.0 for annotation.

EPOCH		Lambton County		Niagara Peninsula
SILURIAN	UPPER	Bass Islands		Bertie
		G Unit	SALINA GROUP	G Unit
		F Unit		F Unit
		E Unit		E Unit
		D Unit		
		C Unit		C Unit
		B Unit		B Unit
		A-2 Unit		A-2 Unit
		A-1 Unit		A-1 Unit
	MIDDLE	Guelph		Guelph
		Goat Island	AMABEL	Goat Island
		Gasport		Gasport
		Rochester		Rochester
				Irondequoit
		Reynales		Reynales
				Thorold
	LOWER	Cabot Head	CATARACT	Grimsby
				Cabot Head
		Manitoulin		Manitoulin
				Whirlpool
U. ORD.		Queenston		Queenston

Figure 4: Silurian stratigraphic relationships for Lambton County study area. Based on Johnson et al (1992), Winder and Sanford (1972) and Sanford (1969).

Regional Structures

Lambton County and Sombra Township are located on the northwest flank of the Algonquin Arch and the southeastern margin of the Michigan Basin. The Rochester Formation is a dolomitic shale of regional extent with little or no depositional relief and is widely used by Ontario geologists for mapping regional structures and faults. Within the study area the Rochester Formation forms a low-relief ramp of with a regional dip of approximately 8 m/km to the northwest. The Rochester surface is broken in the southern part of Sombra Township by several faults (Fig.5). The Dawn Fault is a prominent regional structure in the southern portion of Lambton County and is clearly defined on the Rochester surface in the southeast corner of Sombra Township. The fault is essentially vertical and displaces the Rochester Formation top downward as much as 22 m on the south side of the fault. Outside the study area this fault displays up to 47 m of displacement (Brigham, 1971). A complex of less prominent faults referred to here as the Becher faults can also be mapped on this surface. These structures are also clearly visible on the A2-Carbonate surface (Fig.8) in addition to the Electric Fault south of the Dawn Fault. The Electric Fault displays more than 100 metres of vertical displacement (Brigham, 1971)

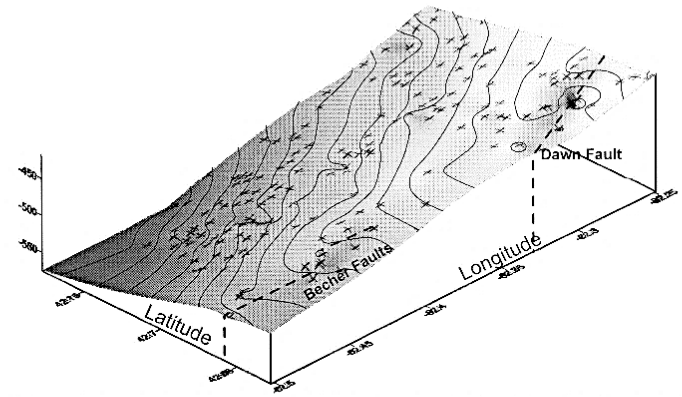


Figure 5: Overlaid contour and 3D surface maps of structure top map of Rochester Formation in Sombra Township. Location of Dawn and Becher faults are indicated with dashed lines. Contour interval is 10 metres. The map is based on data from 180 wells shown as crosses on the map. Vertical exaggeration is approximately 12x.

Reefs

During deposition of the Guelph Formation the warm seas flooding the North American craton were ideal for reef growth and later for evaporite deposition. A thick carbonate platform and barrier reef complex developed in the shallow waters around the fringes of the Michigan Basin and over the crest of the Algonquin Arch (Fig.6). A discontinuous belt of pinnacle reefs developed on the slope between the carbonate platform to the east and the deeper waters of the basin to the west (Carter et al, 1994). The reefs have relief of 100 to 120 metres above the regional Guelph surface and are clearly visible on the 3D surface map (Fig.7)

Reef Burial

The Guelph Formation is unconformably overlain by carbonates, dolomitic shales and evaporites of the Salina Group (Fig.6). Regionally the salt-bearing A, B, D and F units thicken from the edge of the Guelph carbonate platform into the Michigan Basin, whereas the C, E and G units and the non-evaporitic portions of the F Unit remain relatively constant in thickness (Sanford, 1969). Within the study area this reduces the regional dip into the Michigan Basin from 8 m/km at the top of the Rochester Formation to less than 5 m/km at the top of the Salina G Unit. The A-1 Unit averages 40 m in thickness in the study area, burying the basal portions of the underlying reefs. The reefs are completely covered by the overlying A-2 Carbonate Unit but their location is still discernable on the 3D surface due to compaction and draping of the A-2 Carbonate over the underlying reefs (Fig.8)

Figure 6: Paleogeography of southern Ontario during deposition of the Guelph Formation.

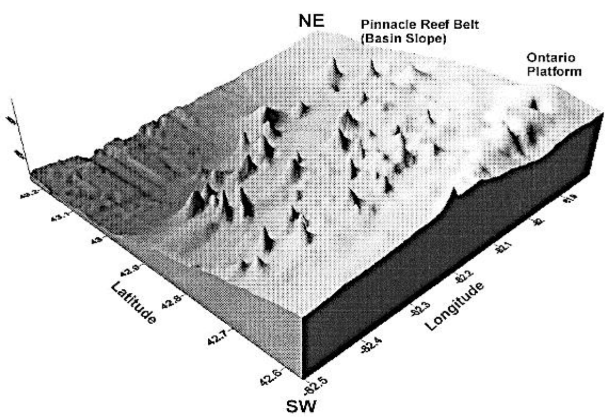


Figure 7: 3D surface map of pinnacle reef belt in Lambton County.

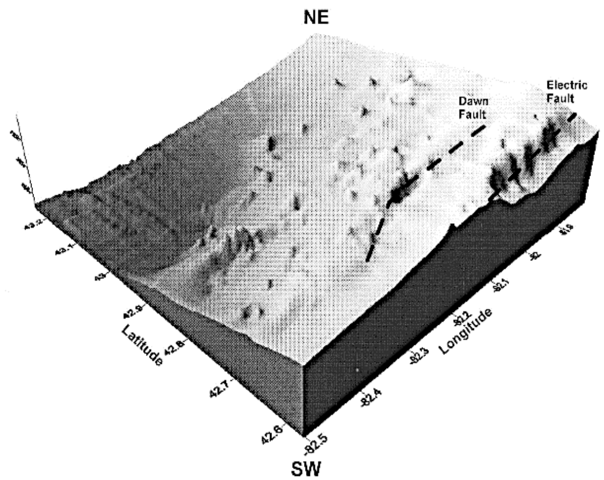


Figure 8: Same area as Figure 7 showing limestone and dolomite of A-2 Carbonate draped over underlying Guelph Formation pinnacle reefs. Dashed lines show fault locations.

Salt Deposition and Dissolution and Collapse of Overlying Strata

The B Unit consists predominantly of salt with interbeds of anhydrite and dolomite. Salt of the B Unit was originally deposited over most of southern Ontario west of the Guelph platform and completely covered the pinnacle reefs (Sanford, 1969, 1976). Salt thickness of the B Unit in southern Ontario varies from zero to nearly 100 m in the Sarnia area.

There has been widespread post-depositional dissolution of Salina salt beds in the subsurface of southern Ontario (Grieve, 1955; Sanford, 1969, 1976). Dissolution edges are often very steep with salt thickness in the B Unit thinning from as much as 90 m to zero in as little as one to two kilometres. There is a close association of many dissolution features with faults. Similarly there has been preferential dissolution of salt over the crests of some pinnacle reefs in southern Ontario (Fig.9). Overlying strata have either collapsed into these dissolution features or have thickened and partially filled the resulting structural depression, depending on the timing of salt dissolution. Careful mapping of the variations in thickness and structure of the overlying strata can be used to resolve this timing.

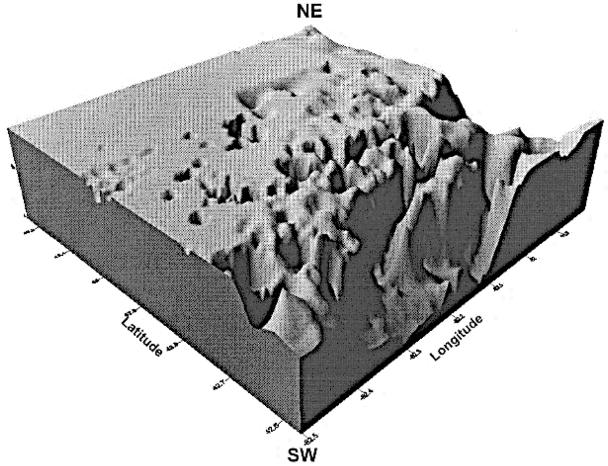


Figure 9: Isopach map of the B Unit for same area in Lambton County as Fig.7 and 8. Linear depressions are salt dissolution and collapse adjacent to faults. Circular depressions are dissolution features over pinnacle reefs. Thickness values have been truncated at a maximum of 90 metres to remove gridding anomalies.

DISCUSSION

The use of well databases and gridding and contouring software to produce subsurface geological maps is not new in the petroleum industry. What is new in the present study is the availability of reliable subsurface geological and well attribute data and digital base maps for most of southern Ontario, use of relatively low cost technology, the use of GIS software and the availability of a made-in-Ontario mapping technique. The ease and speed of digital mapping makes it feasible to map any and all stratigraphic horizons of possible interest whereas previously this was not practical. Of particular value is the ability to create 3-dimensional views of the data and manipulate the displayed results using colour fills, different sun angles, rotation, tilting, etc. This greatly facilitates geological interpretation and produces images that are more readily understood by the non-specialist. This is a powerful new interpretive tool for Ontario geoscientists and should be a practical tool for oil and gas exploration, groundwater studies, bedrock resource studies, contaminant migration studies, etc as well as its obvious application as a research tool for stratigraphic and structural studies. Further detailed mapping using PetroGIS or similar technology could be used to resolve the extent and timing of salt dissolution in southern Ontario and its effects on structure and deposition of younger strata.

OPDS and PetroGIS are works in progress that require continual updating and modification to maintain and improve their capabilities. Future development of OPDS and PetroGIS will add modules for representation and display of horizontal and directionally drilled wells, geophysical well logs, geological cross-sections and fluid analyses. Upgrade and migration of the existing Arcview 3.2 application to ArcView 8.3 has begun with a target implementation date in late 2004.

CONCLUSIONS

Ontario geoscientists now have access to digital base maps of Ontario and a set of affordable, easy-to-use GIS tools linked to a modern relational database of geo-referenced and verified subsurface geological data. When combined with commercially available gridding and contouring software capable of three-dimensional representation of geological surfaces and volumes it provides a powerful new visualization tool for geoscientists. When used by a competent geoscientist applying sound and proven geological concepts this should stimulate development of new ideas and interpretations and provide new tools with which to test them.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contribution made by all those who contributed to development of OPDS over a period of nearly 40 years, beginning in 1963 with the work of J. F. Hart and R. Brigham at the University of Western Ontario and D.A. Sharp of the Ontario Department of Mines and Northern Affairs (Brigham, 1971). The present version of OPDS resulted from the work of a project team including Terry Carter, Cathy Owen, Rudy Rybansky, Ian Cameron, Wendy Sullivan and Jug Manocha. All staff of the Centre, past and present, contributed to data collection, data entry and editing, and ensuring data quality and integrity. In particular we acknowledge the thousands of hours of data entry and editing by staff of the Oil, Gas and Salt Resources Library using funding provided by the Oil, Gas and Salt Resources Trust. Present staff members include Michael Dorland, Richard Ostrowski, Kevin Bartlett, Edith Luther, Naamat Osman and Theresa Serwatuk. Jamie Alexander completed formation top picks for Sombra Township.

Development of PetroGIS began in the summer of 2000 in a cooperative project sponsored by the Petroleum Resources Centre and the South-central Region office of the Ministry of Natural Resources assisted by funding from the Summer Experience Program of the Ontario government. Greg Pawlett, Jean Blondin and Kyle Davey completed initial design, programming and implementation with subsequent modifications and upgrades by Mike Dunkley and Arthur Castillo. The Arcview tool for extraction of geological formation tops was designed and programmed by Arthur Castillo. Terry Carter defined business requirements.

REFERENCES

Beards, R.J., 1967, Guide to the subsurface Palaeozoic stratigraphy of southern Ontario: Ontario Department of Energy and Resources Management, Paper 67-2, 19 p, 8 enclosures.

Brigham, R.J., 1971. Structural geology of southwestern Ontario and southeastern Michigan: Ontario Department of Mines and Northern Affairs, Paper 71-2, 110 p.

Brigham, R.J., and Sharp, D.A., 1965. Computers will record Ontario oil and gas data: Oil and Gas Journal, October 11, 1965, p.242-246.

Carter, T.R., 1990, Some notes on the geological setting and petroleum resources of southwestern Ontario, *in* Subsurface geology of southwestern Ontario – a core workshop: Ontario Petroleum Institute, 146 p.

Carter, T.R., 1991, Dolomitization patterns in the Salina A-1 and A-2 Carbonate Units, Sombra Township, Ontario: Ontario Petroleum Institute, Proceedings Vol.30, Paper No. 4, 35 p.

Carter, T.R., 2001, Digital well data for Ontario – a progress report: Ontario Petroleum Institute, Proceedings Vol.40, Paper No. 4, 8 p.

Carter, T.R., Trevail, R.A., and Smith, L., 1994. Niagaran reef and inter-reef relationships in the subsurface of southwestern Ontario: Geological Association of Canada – Mineralogical Association of Canada, Joint Annual Meeting, Waterloo 1994, Field Trip A5: Guidebook, 38 p.

Golden Software Inc, 2002, Surfer 8 user's guide – contouring and surface mapping for scientists and engineers: Golden Software Inc, 640 p.

Grieve, R.O., 1955. Leaching (?) of Silurian salt beds in southwestern Ontario as evidenced in wells drilled for oil and gas: Canadian Institute of Mining and Metallurgy, Transactions v.58, p.12-18.

Hurd, D.B., and Ostreicher, D.C., 1977. The new petroleum resources data system: Ontario Petroleum Institute, vol.16, Paper No. 9

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.907-1008.

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

Sanford, B.V., 1969. Silurian of southwestern Ontario: Ontario Petroleum Institute, paper 5, 44 p.

Sanford, B.V., 1976, Silurian-Devonian of southwestern Ontario: Geological Survey of Canada, Open File Report 401, 5 maps, 5 cross-sections, 1 chart.

Sanford, B.V., and Quillian, R.G., 1959, Subsurface stratigraphy of Upper Cambrian rocks in southwestern Ontario: Geological Survey of Canada, Paper 58-12, 33 p.

Uyeno, T.T., Telford, P.G., and Sanford, B.V., 1982, Devonian conodonts and stratigraphy of southwestern Ontario: Geological Survey of Canada, Bulletin 332, 55 p.

Winder, C.G., and Sanford, B.V., 1972, Stratigraphy and paleontology of the Paleozoic rocks of southern Ontario: XXIV International Geological Congress, Montreal, Quebec, Excursion A45-C45

Acknowledgements

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Paul Hubert (Deputy Mayor, City of London)
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GoGeomatics Canada is a community driven effort to promote and organize the geospatial community in Canada locally from the grassroots. We consist of 14 geospatial networking groups in cities across Canada. To date, we have hosted 300 plus free networking events. Our annual 'Back to School Socials' are now on their 5th year and attract 400 or more participants. These geospatial events are organized across the country, by 40 volunteers who lead the vibrant online community.

In the magazine, Canadian geomatics organizations post their jobs, news, and events. We are close to publishing our 1,000th Canadian geomatics article, and our Canadian Spatial Times newsletter has 7,000+ subscribers. GoGeomatics Canada is the most popular magazine in Canada's geospatial sector for geospatial news, events, jobs, community engagement, and communications.

We have groups in Calgary, Edmonton, Halifax, Kelowna, Kingston, London, Niagara, Ottawa, Peterborough, Thunder Bay, Toronto, and Vancouver. As well new groups in Regina and Fredericton.

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Please take time to complete the survey enclosed in this program. Your feedback is much appreciated and incredibly valuable in helping us to deliver a better conference for you next year.

Return your completed survey to the registration desk.

See you in 2019!

Core Photos

The OGSR Library catalogues 1,185 rock cores from 999 different Paleozoic wells from all parts of Ontario, including several from the far north basins. The OGSR Library rock core and rock chip (~13,000 locations) catalogue represents Ontario's most significant and comprehensive resource for Paleozoic rock research and direct access to deep Paleozoic bedrocks.

These cores are accessible to anyone for research purposes. A selection of cores was prepared by OGSR Library for EPEX to create an immersive hands-on experience with the geology and demonstrate cores can be found for just about any research purpose. The cores listed below have been matched to the relevant EPEX Blocks and sample photos can be found on the pages that follow.

Block 1 – Energy Storage

Photo 1: Well Licence T003563, Core 1072, Box 96, Top Depth 331.32 meters, Dry

Significance: Salt mining, salt solution mining, cavern storage and compressed air energy storage

Photo 2: Well Licence T005813, Core 751, Box 187, Top Depth 443.2 meters, Wet

Significance: Natural gas storage in Guelph fm.

Block 2 – Environment and Resource Management

Photo 3: Well Licence T006078, Core 861, Box 49, Top Depth 153.0 meters, Wet

Significance: Amherstburg fm., can be regional aquifer, salty or sulphurous, can exhibit artesian flow

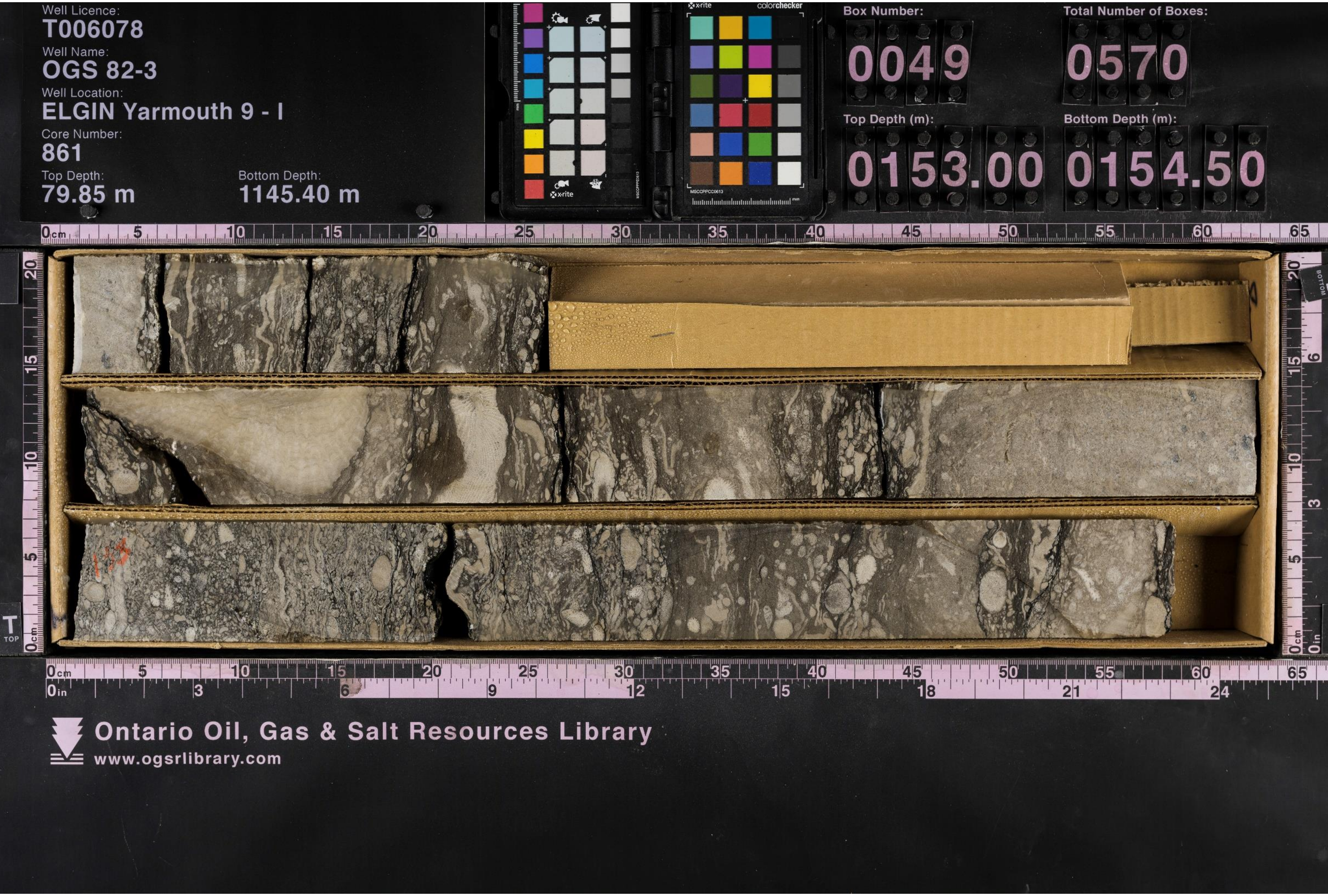
Block 3 – Hydrocarbons

Photo 4: Well Licence T007529, Core 595, Box 5, Top Depth 120.4 metres, Wet
Photo 5: Well Licence T007529, Core 595, Box 5, Top Depth 120.4 metres, Ultraviolet Fluorescence

Significance: Dundee fm. oil staining


Well Licence:
T003563
Well Name:
DOMTAR GODERICH S.T.#1
Well Location:
HURON Goderich 2 - MC
Core Number:
1072
Top Depth:
87.17 m
Bottom Depth:
498.96 m
Box Number:
0096
Total Number of Boxes:
0159
Top Depth (m):
0331.32
Bottom Depth (m):
0334.37
Ontario Oil, Gas & Salt Resources Library
www.ogsrlibrary.com

Well Licence:
T005813
Well Name:
Consumers 33409
Well Location:
KENT Tilbury East 4 - IX
Core Number:
751
Top Depth:
91.60 m
Bottom Depth:
549.30 m
Box Number:
0187
Total Number of Boxes:
0248
Top Depth (m):
0433.20
Bottom Depth (m):
0435.40
Ontario Oil, Gas & Salt Resources Library
www.ogsrlibrary.com



Well Licence:
T006078
Well Name:
OGS 82-3
Well Location:
ELGIN Yarmouth 9 - I
Core Number:
861
Top Depth:
79.85 m
Bottom Depth:
1145.40 m
Box Number:
0049
Total Number of Boxes:
0570
Top Depth (m):
0153.00
Bottom Depth (m):
0154.50
Ontario Oil, Gas & Salt Resources Library
www.ogsrlibrary.com

Well Licence:
T007529
Well Name:
Imperial 831 (GBS-26)
Well Location:
LAMBTON Enniskillen 18 - I
Core Number:
595
Top Depth:
100.89 m
Bottom Depth:
133.81 m
Box Number:
0005
Total Number of Boxes:
0008
Top Depth (m):
0120.40
Bottom Depth (m):
0123.93
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