Appalachian Basin Unconventional Reservoirs - A Discussion of Past, Present and Future Play Trends*

William A. Zagorski[1]

Search and Discovery Article #80414 (2014)**
Posted October 27, 2014

*Adapted from oral presentation given at All-Convention Luncheon, Tuesday, September 30, 2014, AAPG 42nd Eastern Section Meeting, London, Ontario, Canada, September 27-30, 2014

[1]Range Resources - Appalachia LLC, Southpointe, PA, USA (bzagorski@rangeresources.com)

Abstract

Development of unconventional self-sourced reservoirs has a long established history in the Appalachian Basin dating back to the early 1800'S. In the early 1820'S, a robust shale gas industry started and thrived along the US portion of Lake Erie and Lake Ontario across portions of New York, Pennsylvania, and Ohio into the early 20th century. Early attempts were made to commercially retort oil from the Ordovician Age Collingwood shale in Ontario pre date the Canadian discovery at Oil Springs and Petrolia in Ontario and the US Drake discovery at Titusville, Pennsylvania. Large-scale development of gas from the Upper Devonian Shale was achieved with the discovery of the Big Sandy field in Kentucky in the early 1920'S. The large-scale commercialization of the Upper Devonian Age Marcellus shale was initiated in Pennsylvania in late 2004 through 2007 and has now become one of the world's most prolific gas plays. The Ordovician Age Utica Point Pleasant was successfully tested in Quebec in 2006 through 2009 and commercially developed in Ohio and Pennsylvania since 2010 and continues to expand now into West Virginia and southwestern Pennsylvania. Both the Marcellus Shale and Utica Point Pleasant plays represent key milestones in re-establishing the Appalachian Basin as a prominent producing region. This presentation will provide a review of the past, present, and future potential of unconventional resource development in the Appalachian Basin region.

Selected References

Carter, T., L. Fortner, and C. Béland-Otis, 2009, Shale gas opportunities in southern Ontario — an update: 48th Annual OPI Conference and Trade Show in Sarnia, Canada.

Goodman, W.R., and T.R. Maness, 2008, Michigan's Antrim Gas Shale Play—A Two-Decade Template for Successful Devonian Gas Shale Development: AAPG Annual Convention, San Antonio, TX. April 20-23, 2008. AAPG Search and Discovery Article #10158. Web Accessed October 15, 2014. http://www.searchanddiscovery.net/documents/2008/08126goodman/ndx_goodman.pdf.

Hulver, M.L., 1997, Post-orogenic evolution of the Appalachian mountain system and its foreland: Chicago, Ill., University of Chicago, Ph.D. dissertation, 1055 p.

Lash, G.G., 2014, Authigenic barite nodules and carbonate concretions in the Upper Devonian shale succession of western New York – a record of variable biogenic methane: AAPG Eastern Section Meeting, London, Ontario, Canada. AAPG Search and Discovery Article #90195. Web Accessed October 15, 2014. http://www.searchanddiscovery.com/abstracts/html/2014/90195eastern/abstracts/21.html.

Marcil, J.-S., P.K. Dorrins, J. Lavoie, N. Mechti, and J.-Y. Lavoie, 2012, Utica and other Ordovician shales: Exploration history in the Quebec sedimentary basins, eastern Canada: AAPG Search and Discovery Article #10451, 57 p. http://www.searchanddiscovery.com/documents/2012/10451marcil/ndx_marcil.pdf

Roliff, W.A., 1949, Salina-Guelph fields of southwestern Ontario: AAPG Bulletin, v. 33, p. 153-188

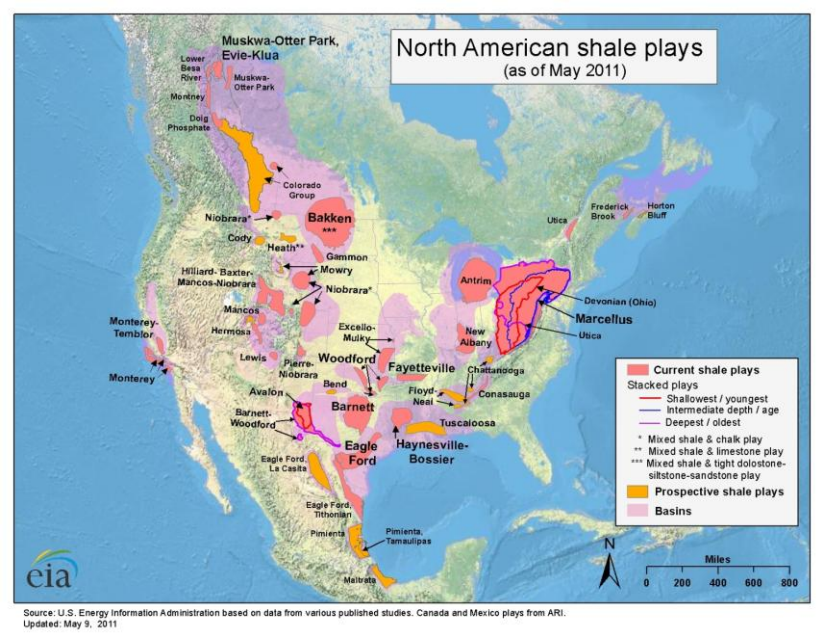
Rowan, E.L., 2006, Burial and thermal history of the central Appalachian basin, based on three 2-D models of Ohio, Pennsylvania, and West Virginia: U.S. Geological Survey Open-File Report 2006–1019, 35 p.

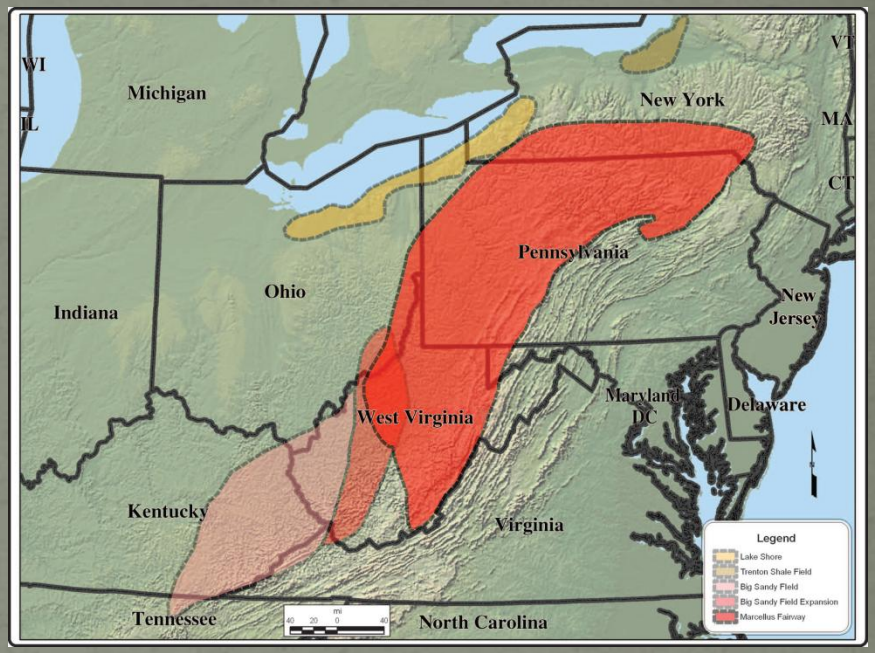
Ryder, R.T., D.C. Harris, P. Gerome, T.J. Hainsworth, R.C. Burruss, P.G. Lillis, D.M. Jarvie, and M.J. Pawlewicz, 2005, Evidence for Cambrian Petroleum Source Rocks in the Rome Trough of West Virginia and Kentucky, Appalachian Basin: U.S. Geological Survey Open-File Report 2005-1443. Web Accessed October 15, 2014. http://pubs.usgs.gov/of/2005/1443/2005-1443.pdf.

Zagorski, B. 2007, Emerging Shale Gas Plays in the Appalachian Basin: PAPG and SPE Joint Session, Web Accessed October 15, 2014. http://papgrocks.org/JAN%2007%20PAPG%20%20Flyer.pdf

Zagorski, W.A., M. Emery, and D.C. Bowman, 2011, Factors control Marcellus productivity: American Oil & Gas Reporter, v. 54/8, p. 172-180.

Appalachian Basin Unconventional Reservoirs - "A Discussion of Past, Present and Future Play Trends."





William A. Zagorski – Vice President – Geology
Range Resources – Appalachia LLC

2014 Eastern Section AAPG Meeting – London, Ontario
September 30, 2014

RANGE RESOURCES

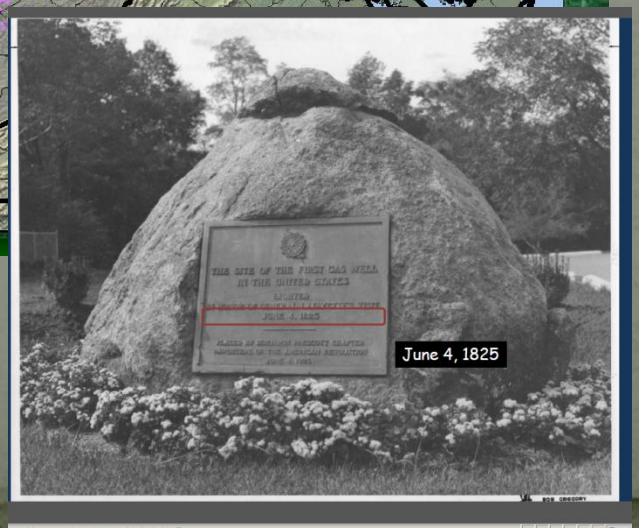
Forward - Looking Statements

Statements concerning well drilling and completion costs assume a development mode of operation; additionally, estimates of future capital expenditures, production volumes, reserve volumes, reserve values, resource potential, resource potential including future ethane extraction, number of development and exploration projects, finding costs, operating costs, overhead costs, cash flow, NPV10, EUR and earnings are forward-looking statements. Our forward looking statements, including those listed in the previous sentence are based on our assumptions concerning a number of unknown future factors including commodity prices, recompletion and drilling results, lease operating expenses, administrative expenses, interest expense, financing costs, and other costs and estimates we believe are reasonable based on information currently available to us; however, our assumptions and the Company's future performance are both subject to a wide range of risks including, the volatility of oil and gas prices, the results of our hedging transactions, the costs and results of drilling and operations, the timing of production, mechanical and other inherent risks associated with oil and gas production, weather, the availability of drilling equipment, changes in interest rates, litigation, uncertainties about reserve estimates, environmental risks and regulatory changes, and there is no assurance that our projected results, goals and financial projections can or will be met. This presentation includes certain non-GAAP financial measures. Reconciliation and calculation schedules for the non-GAAP financial measures can be found on our website at www.rangeresources.com.

The SEC permits oil and gas companies, in filings made with the SEC, to disclose proved reserves, which are estimates that geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions as well as the option to disclose probable and possible reserves. Range has elected not to disclose the Company's probable and possible reserves in its filings with the SEC. Range uses certain broader terms such as "resource potential," or "unproved resource potential," "upside" and "EURs per well" or other descriptions of volumes of resources potentially recoverable through additional drilling or recovery techniques that may include probable and possible reserves as defined by the SEC's guidelines. Range has not attempted to distinguish probable and possible reserves from these broader classifications. The SEC's rules prohibit us from including in filings with the SEC these broader classifications of reserves. These estimates are by their nature more speculative than estimates of proved, probable and possible reserves and accordingly are subject to substantially greater risk of being actually realized. Unproved resource potential refers to Range's internal estimates of hydrocarbon quantities that may be potentially discovered through exploratory drilling or recovered with additional drilling or recovery techniques and have not been reviewed by independent engineers. Unproved resource potential does not constitute reserves within the meaning of the Society of Petroleum Engineer's Petroleum Resource Management System and does not include proved reserves. Area wide unproven, unrisked resource potential has not been fully risked by Range's management. "EUR," or estimated ultimate recovery, refers to our management's internal estimates of per well hydrocarbon quantities that may be potentially recovered from a hypothetical future well completed as a producer in the area. These quantities do not necessarily constitute or represent reserves within the meaning of the Society of Petroleum Engineer's Petroleum Resource Management System or the SEC's oil and natural gas disclosure rules. Our management estimated these EURs based on our previous operating experience in the given area and publicly available information relating to the operations of producers who are conducting operating in these areas. Actual quantities that may be ultimately recovered from Range's interests will differ substantially. Factors affecting ultimate recovery include the scope of Range's drilling program, which will be directly affected by the availability of capital, drilling and production costs, commodity prices, availability of drilling services and equipment, drilling results, lease expirations, transportation constraints, regulatory approvals, field spacing rules, recoveries of gas in place, length of horizontal laterals, actual drilling results, including geological and mechanical factors affecting recovery rates and other factors. Estimates of resource potential may change significantly as development of our resource plays provides additional data. In addition, our production forecasts and expectations for future periods are dependent upon many assumptions, including estimates of production decline rates from existing wells and the undertaking and outcome of future drilling activity, which may be affected by significant commodity price declines or drilling cost increases. Investors are urged to consider closely the disclosure in our most recent Annual Report on Form 10-K, available from our website at www.rangeresources.com or by written request to 100 Throckmorton Street, Suite 1200, Fort Worth, Texas 76102. You can also obtain this Form 10-K by calling the SEC at 1-800-SEC-0330.

1825 – 1900's - Devonian Shale Lake Erie Shoreline

Source: Zagorski 2007

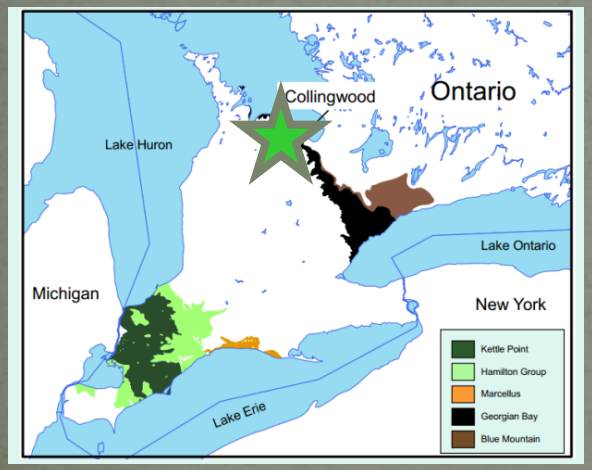


- 1825 Natural Gas Fredonia New York.
- 1825- 1900's shallow gas along Lake Erie Shoreline.
- Produced from shallow depths.
- Some initial high rates but characteristically low volume and pressure.
- Very long production life.
- Important domestic and industrial sources of gas.
- Play had some resurgence in NY, PA and OH in 1980 through 2000.
- Significant shallow shows in Ontario.

Source: AAPG Lash 2014

1859 – 1863 - Collingwood Oil Shale Extraction

Source: Wikipedia



Source: 2012 AAPG -Carter, Fortner, Otis

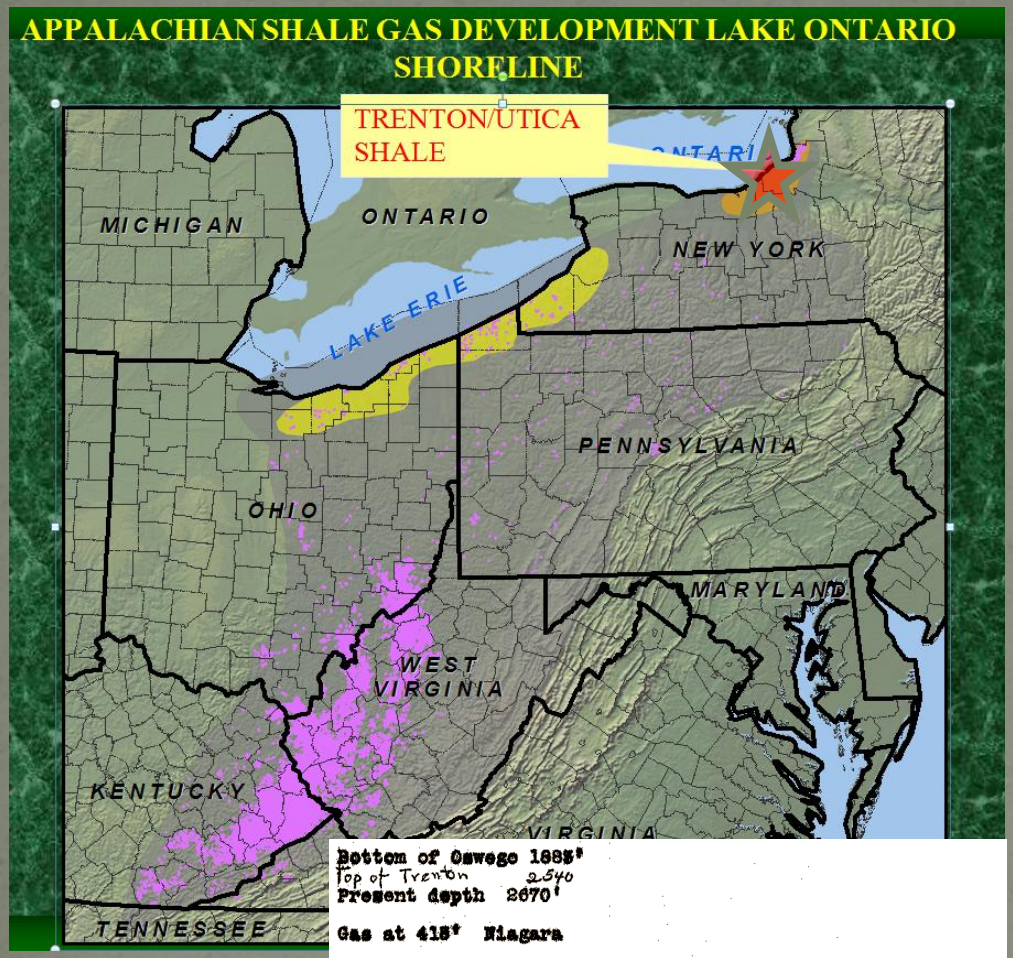
In 1859 – Craigleith Shale Oil Works - Retorted oil shale from member of Collingwood Shale.

TOC content as high as 9.8 per cent.

North American oil discoveries in 1858 and 1859 made operation uneconomic by 1863.

Now a major Appalachian Basin exploration target .

1888 – 1940's - New York Trenton Gas Fields

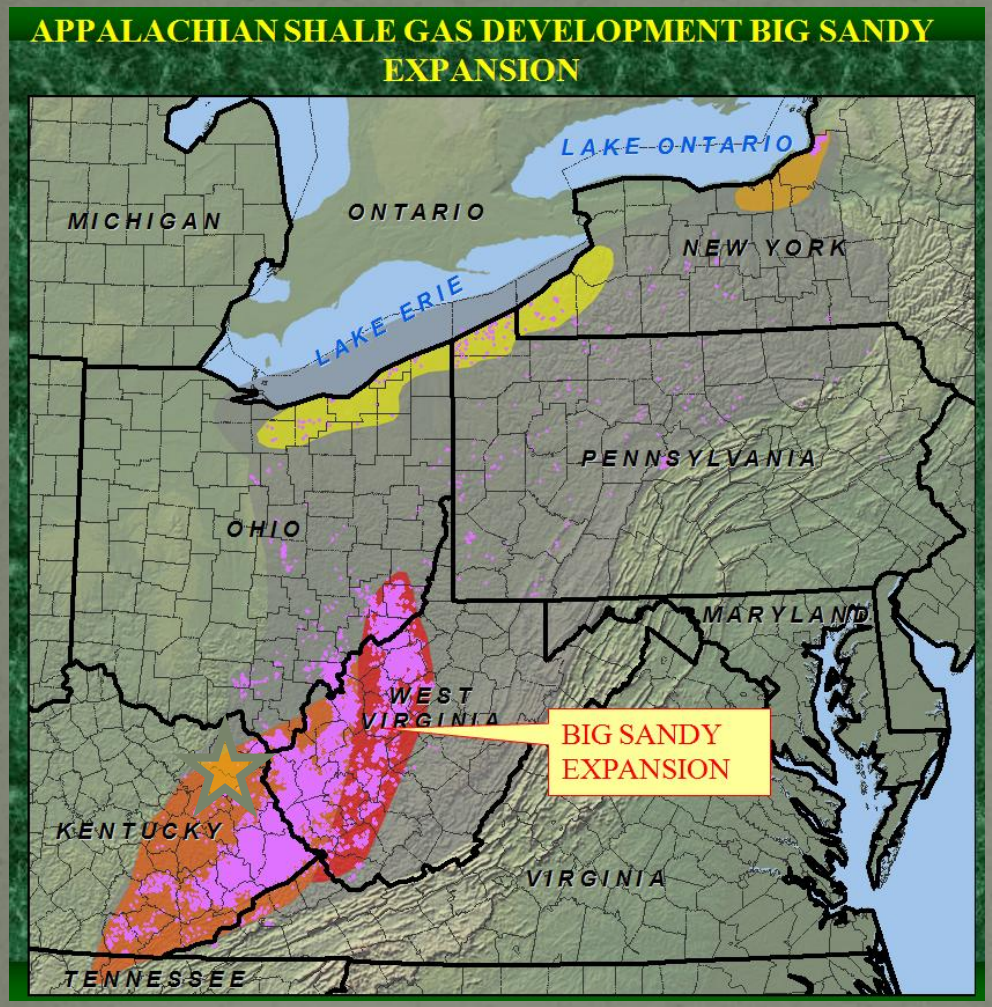


Source: Zagorski 2007

Bottom of Oswego 1885'
Top of Trenton 2540
Present depth 2670'
Gas at 418' Niagara
Gas at 1748' Oswego
Gas at 2670' Trenton
Rig burned, will build new rig according to Boyce and drill deeper.
October 1 log
October 27 12' more
See Gillette's letter of Nov. 7

- 1888 Sandy Creek Field
- Production was from the upper Trenton Limestone.
- Wells were shallow 600' to 2,800'.
- Flow rates and pressures initially high but were low volume producers.
- Early recognized as a shale gas play.
- Activity waned after 1940 and 1960's.

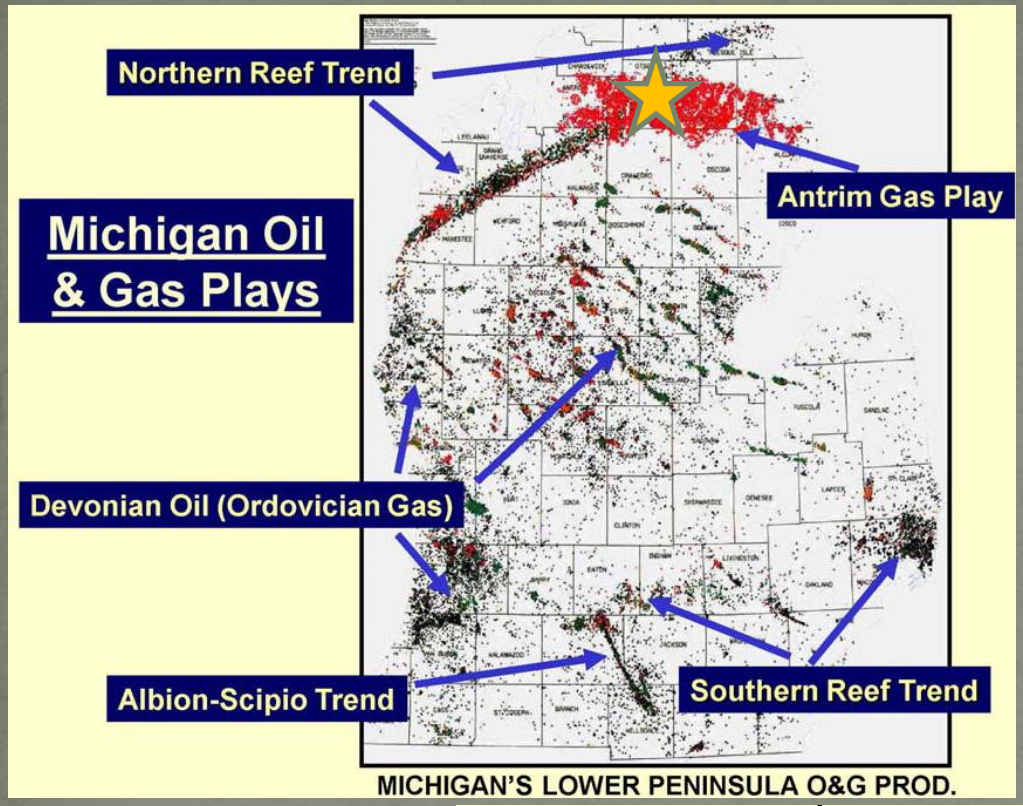
1921- Present - Big Sandy Field – KY, WV, and OH



Source: Zagorski 2007

- Discovered 1921.
- Field produced from moderate depths of 2,000 to 6,500 feet Huron and Rhinestreet members.
- Significantly under pressured.
- Over 21,000 wells drilled.
- Expanded into KY, WV, OH and VA.
- First true unconventional giant field producing over 2.5 TCF to date.
- Focus of many DOE studies in 1980's.
- Still actively developing using horizontal drilling and completion methods.

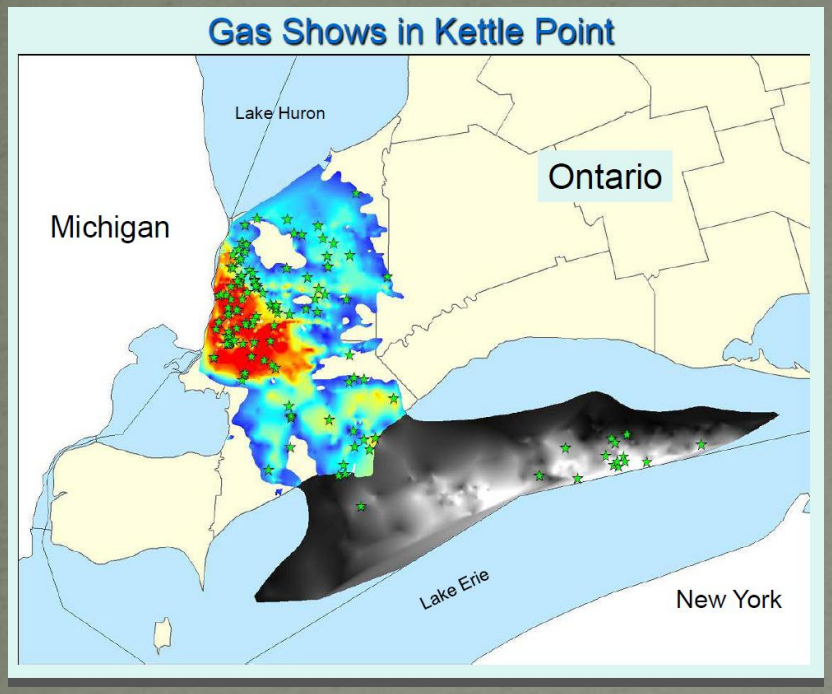
1980 – Present - Antrim and New Albany Shale Plays

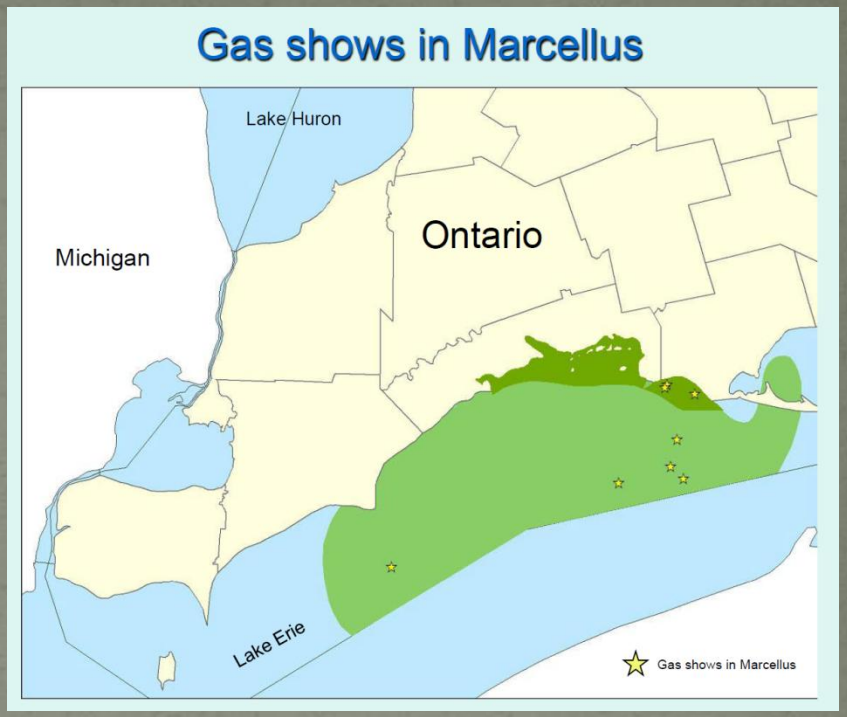


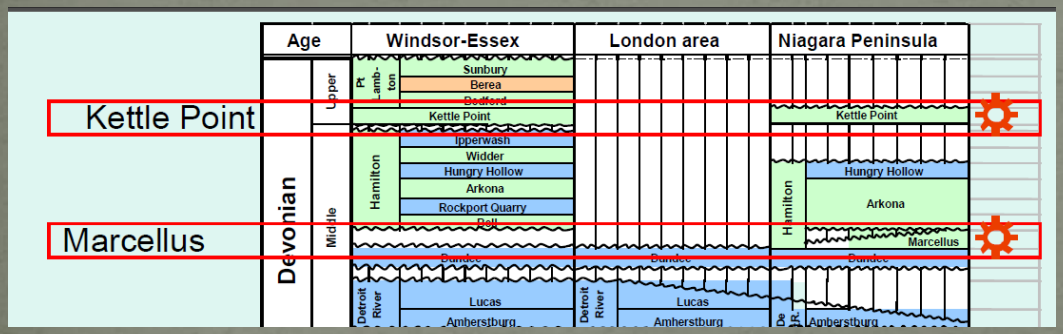
Source: Goodman and Maness, 2008)

- Discovered natural gas early while testing northern reef trend in the 1940's.
- Full development peaked in 1980's.
- Field produced from shallow depths of 500 to 1,500 feet.
- Expanded into Illinois Basin as New Albany Shale Play.
- A true unconventional giant field with over 2.5 TCF to date from approximately 9,000 wells.
- Complicated unconventional trap dominated by natural fracture development and influence of glacial recharge system with an active biogenic sourced gas system.
- Analog for potential Kettle Point shallow gas play in Ontario.

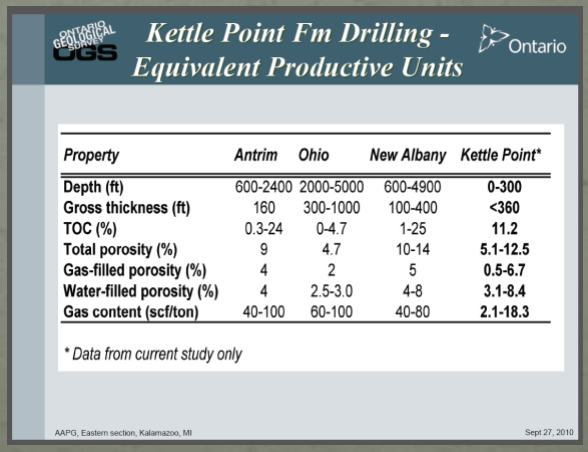
Ontario Kettle Point/Marcellus Shale Plays







Source: AAPG 2009 - Carter, Fortner, Otis



Kettle Point Fm Drilling - Equivalent Productive Units

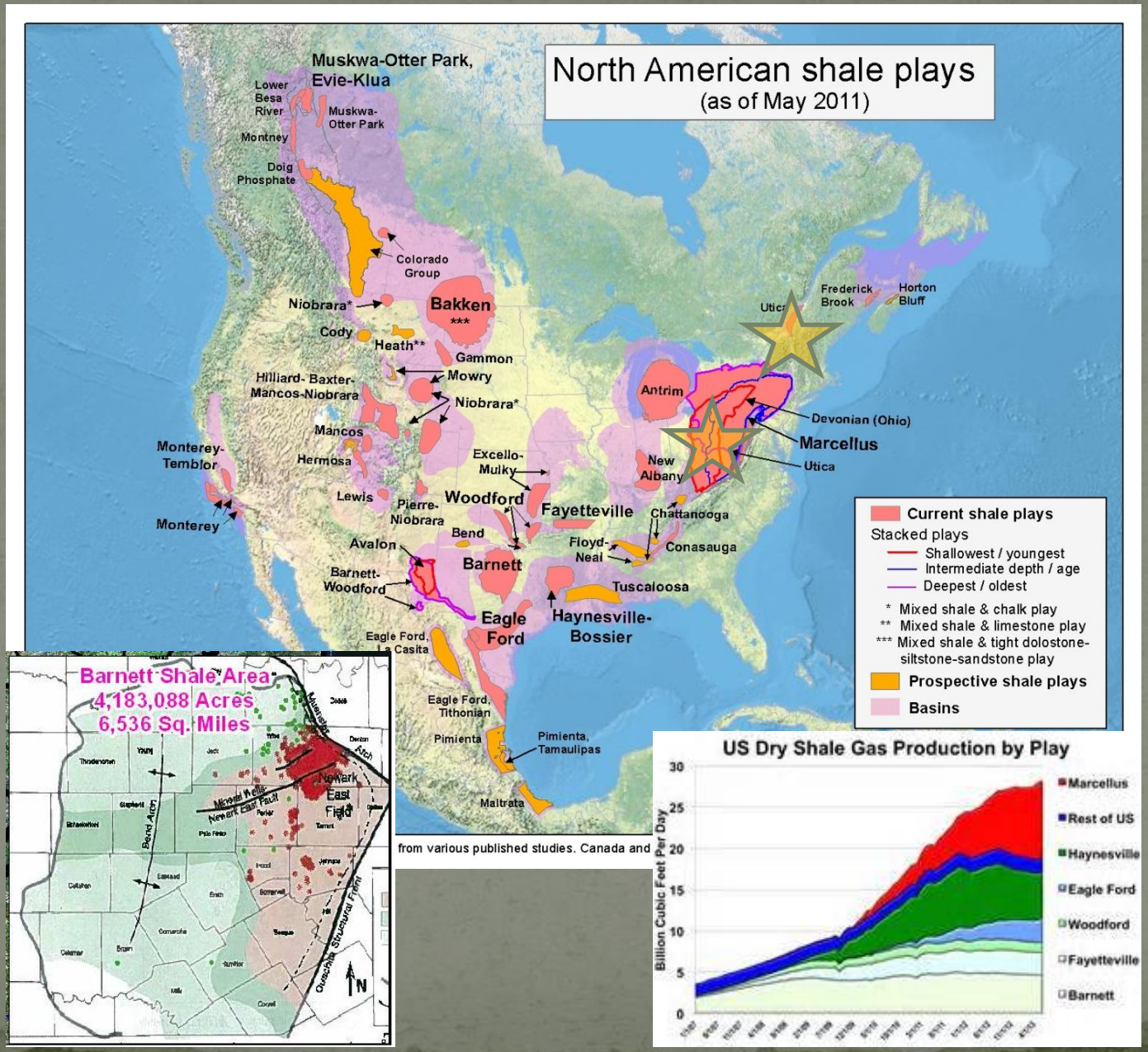
Property	Antrim	Ohio	New Albany	Kettle Point*
Depth (ft)	600-2400	2000-5000	600-4900	0-300
Gross thickness (ft)	160	300-1000	100-400	<360
TOC (%)	0.3-24	0-4.7	1-25	11.2
Total porosity (%)	9	4.7	10-14	5.1-12.5
Gas-filled porosity (%)	4	2	5	0.5-6.7
Water-filled porosity (%)	4	2.5-3.0	4-8	3.1-8.4
Gas content (scf/ton)	40-100	60-100	40-80	2.1-18.3

* Data from current study only

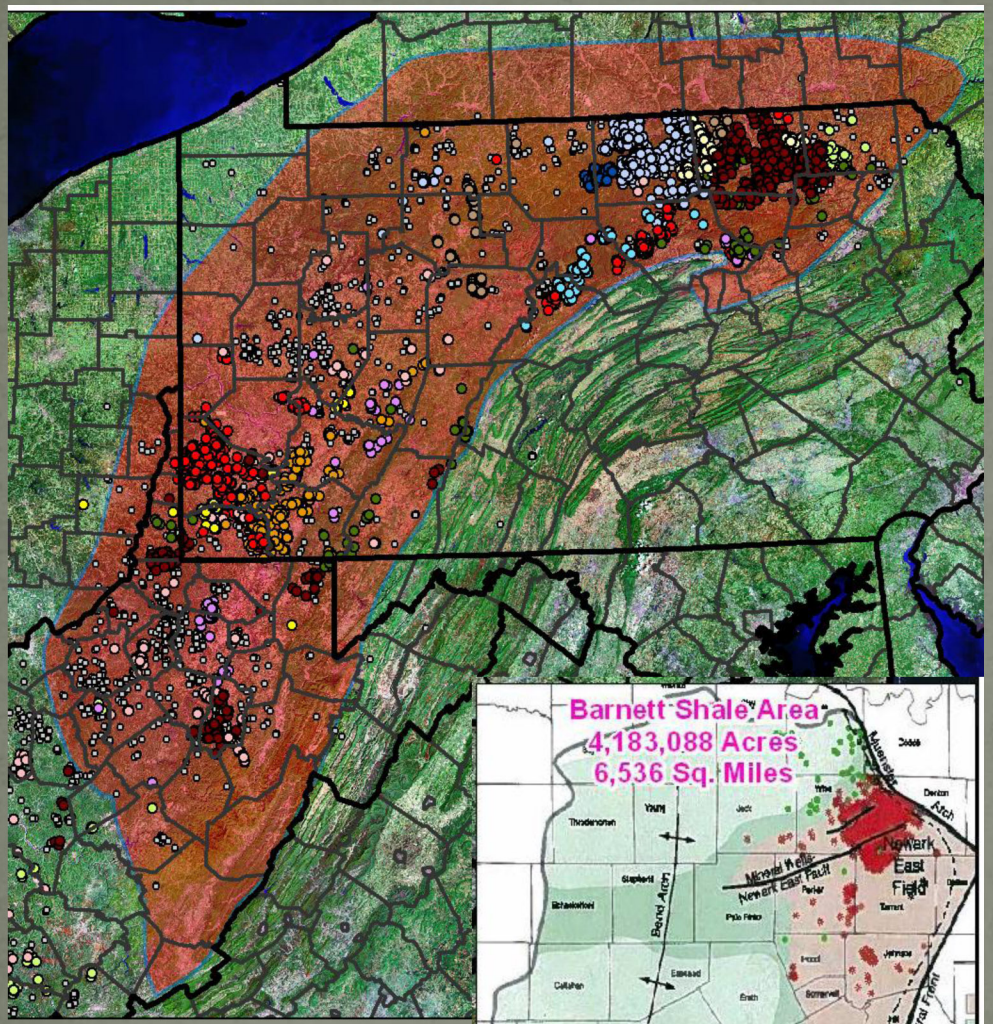
AAPG, Eastern section, Kalamazoo, MI

Sept 27, 2010

2002 – Present - Rise of Modern Shale Gas Plays



2004 – Present - Marcellus Shale Play



Source: Zagorski 2013

Source: AAPG

Prior to 2004 Marcellus was a minor target with limited production in NY, OH, WV and PA.

2004 – First Barnett size fracture on RRC Renz Unit #1 resulted in vertical well commercial discovery.

2007 – Present – Play commercialized horizontally.

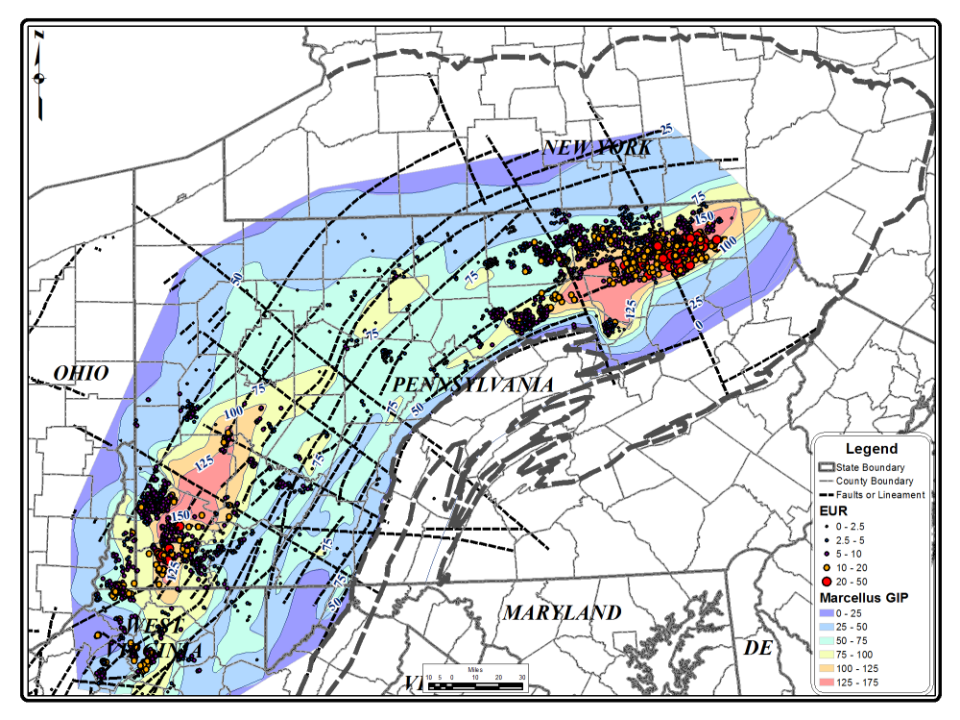
Now expanding to one of as one of largest gas fields/plays in the world.

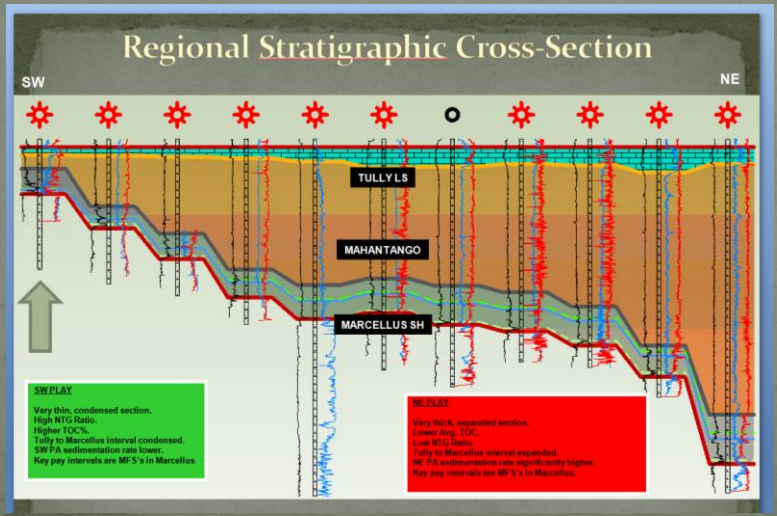
Currently producing 15.9 BCFEPD.

Resource potential estimates from 97 TCF to 490 TCF.

Liquids potential of 4.5 Billion Bbls.

Marcellus Shale Play Overview

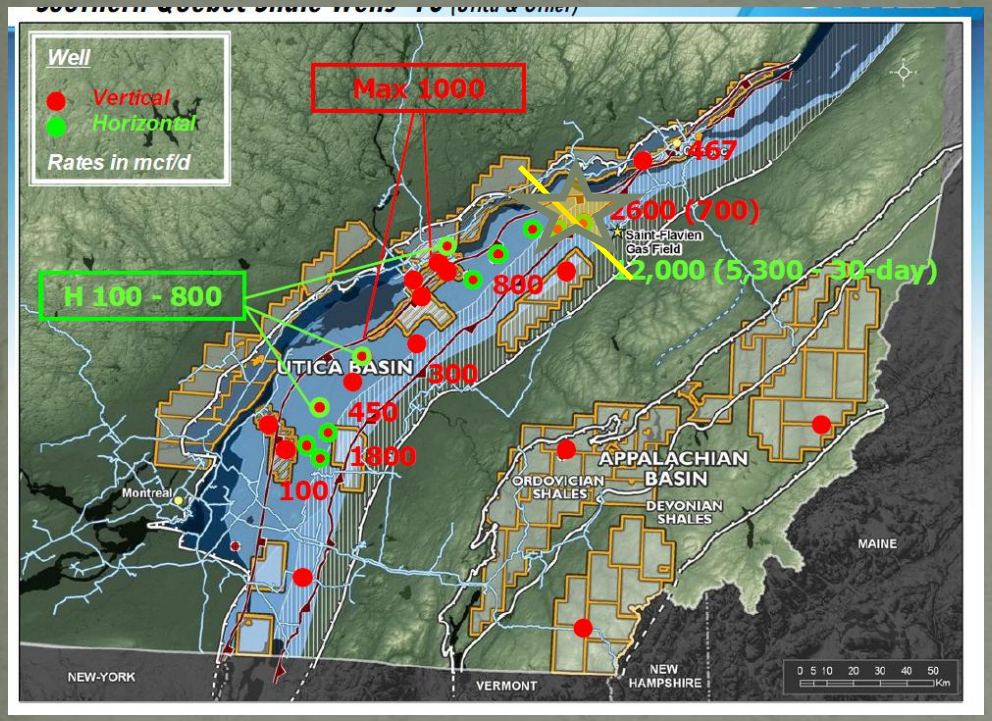




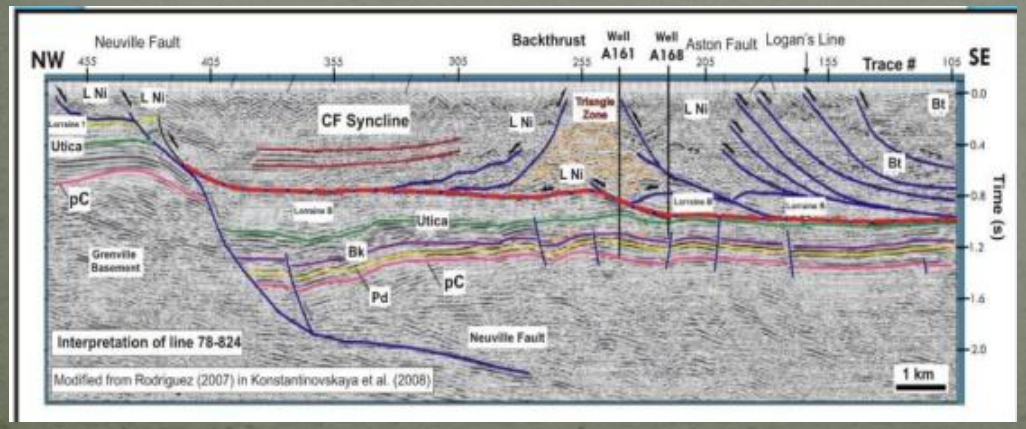
Source: AAPG Zagorski, Emery, Bowman 2011

- Two core areas developed in play, NE dry gas and liquids rich dry gas in SW.
- Significantly different geologic characteristics in each core area.
- Play success driven by rock quality and completion effectiveness and continued innovation.
- Significant potential for future expansion in non core areas.
- Many areas have dual target potential in the deeper Utica Point Pleasant and the shallower Upper Devonian shale plays.
- Selection of lateral target, increased lateral lengths, increasing proppant concentrations and reduced stage spacing all positively impacting play metrics.

2006 – Present - Utica Shale Discoveries - Quebec



Source: AAPG 2012 - Marcil



Source: AAPG 2012 - Marcil

Commercial testing as early as 1978.

Interest in play grew after 2004 as the Barnett matured.

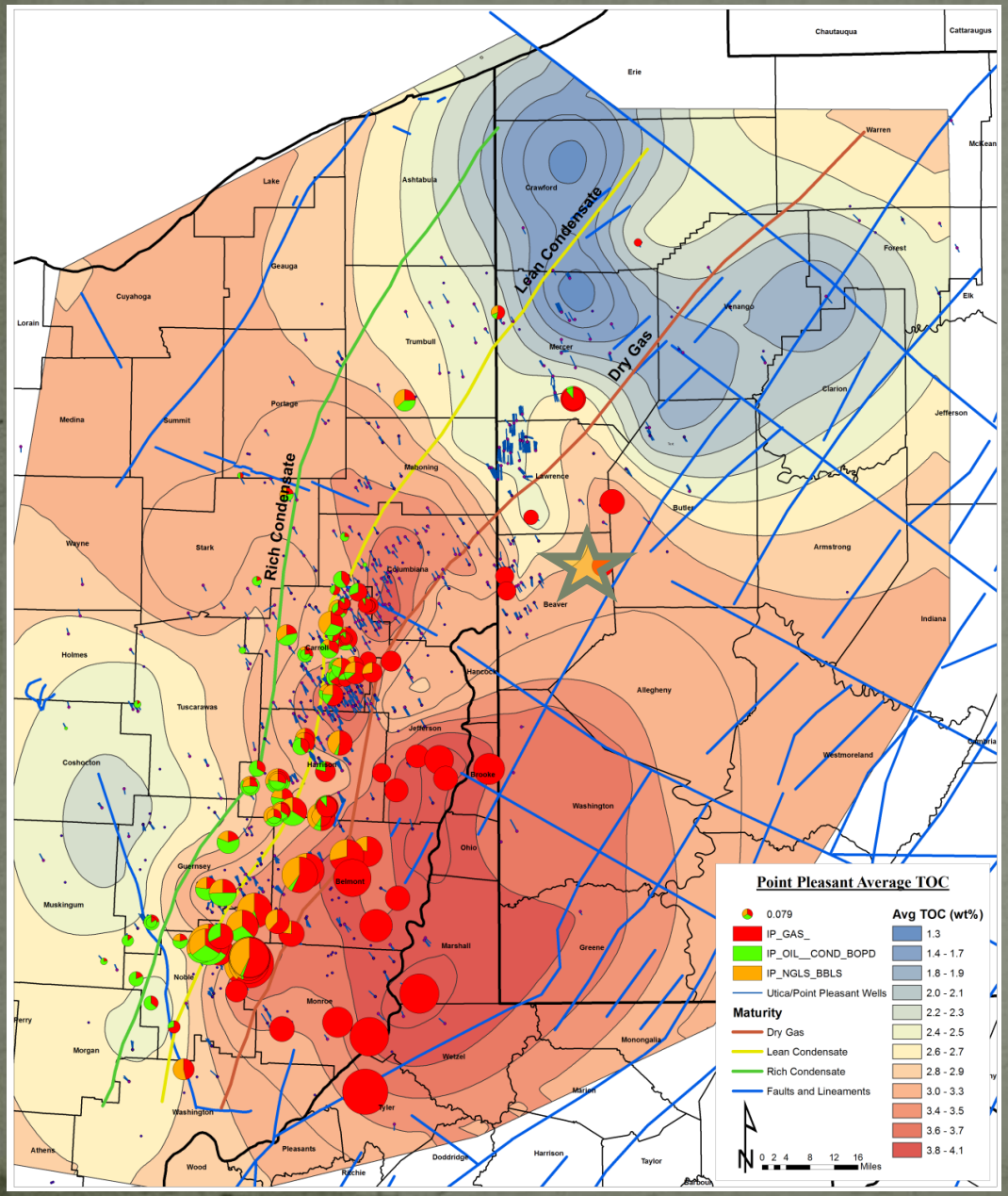
Significant vertical and horizontal testing from 2006 thru 2010.

Test rates of 1 MMCFPD to 12.5 MMCFPD

Resource potential estimated in the 100 to 300 TCF range.

Further testing halted after 2011.

2010 – Present - Point Pleasant Play OH, PA, and WV



Initial vertical testing in 2005 through 2007.

First horizontal Point Pleasant completion in 2010 in Beaver County, PA.

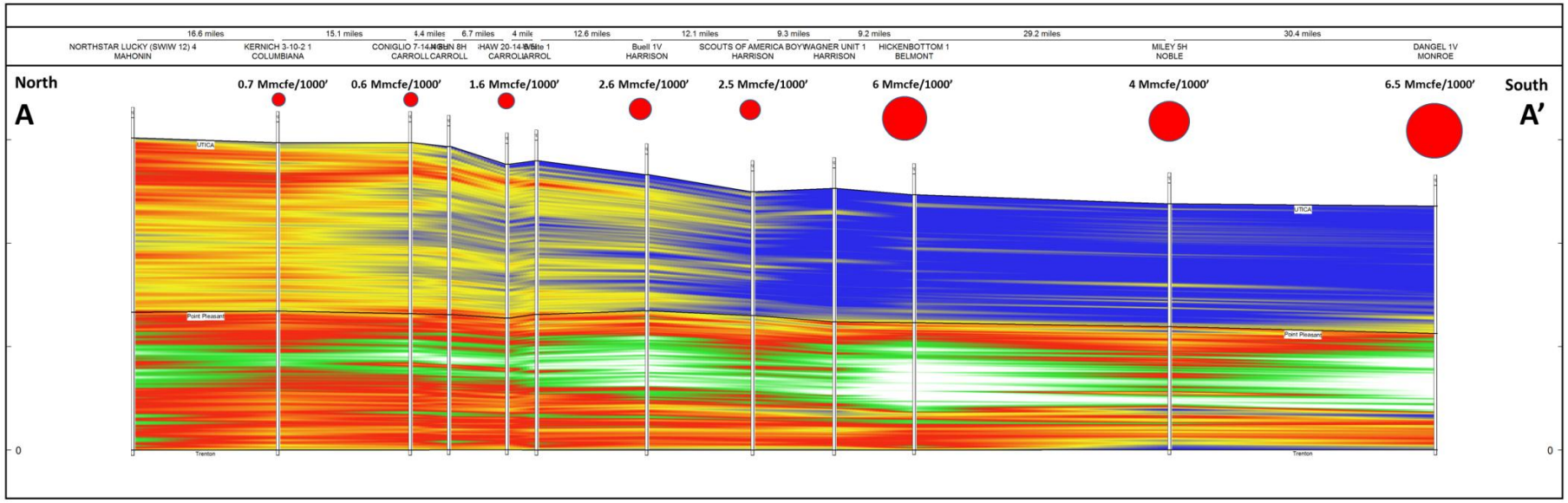
Play gained major momentum in Ohio and PA in 2011.

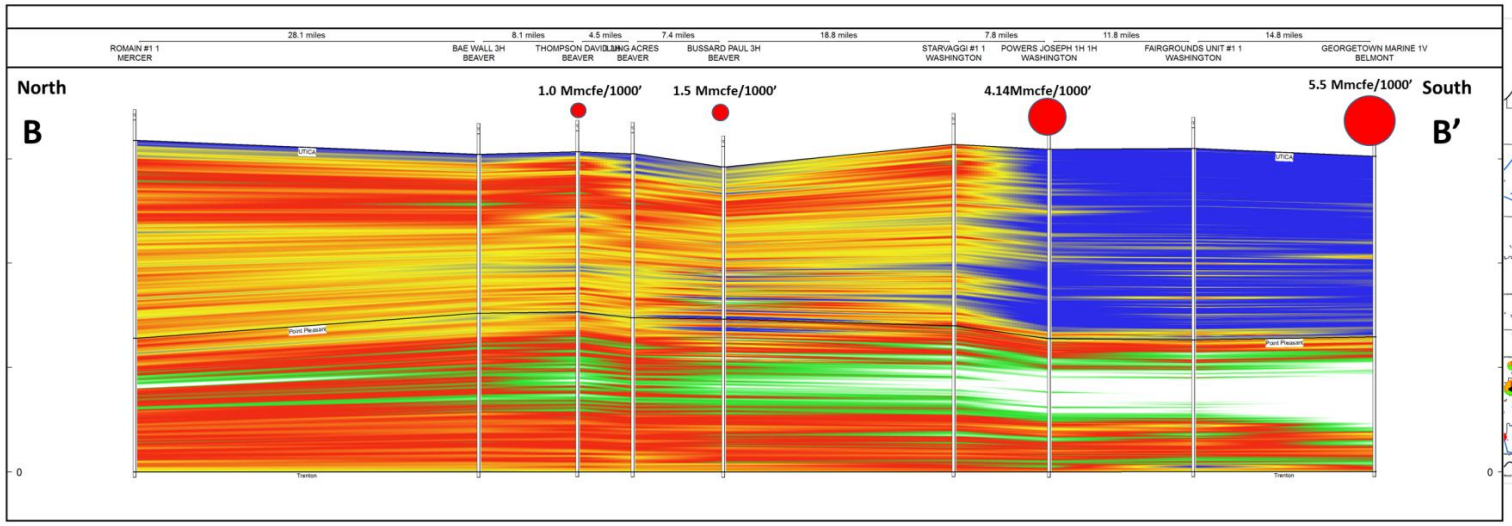
Core area in southeastern OH now expanding to east into WV and PA.

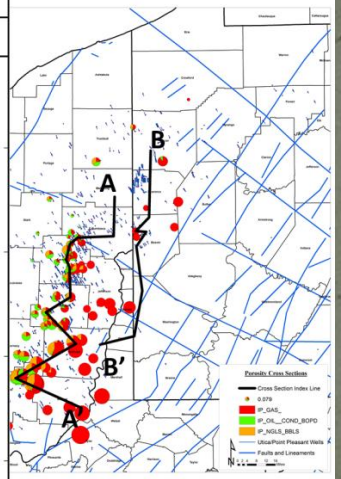
Play is currently producing 1.35 BCFEPD.

Significant exploration in northern WV and southwest PA.

SW Point Pleasant Play – Reservoir Quality

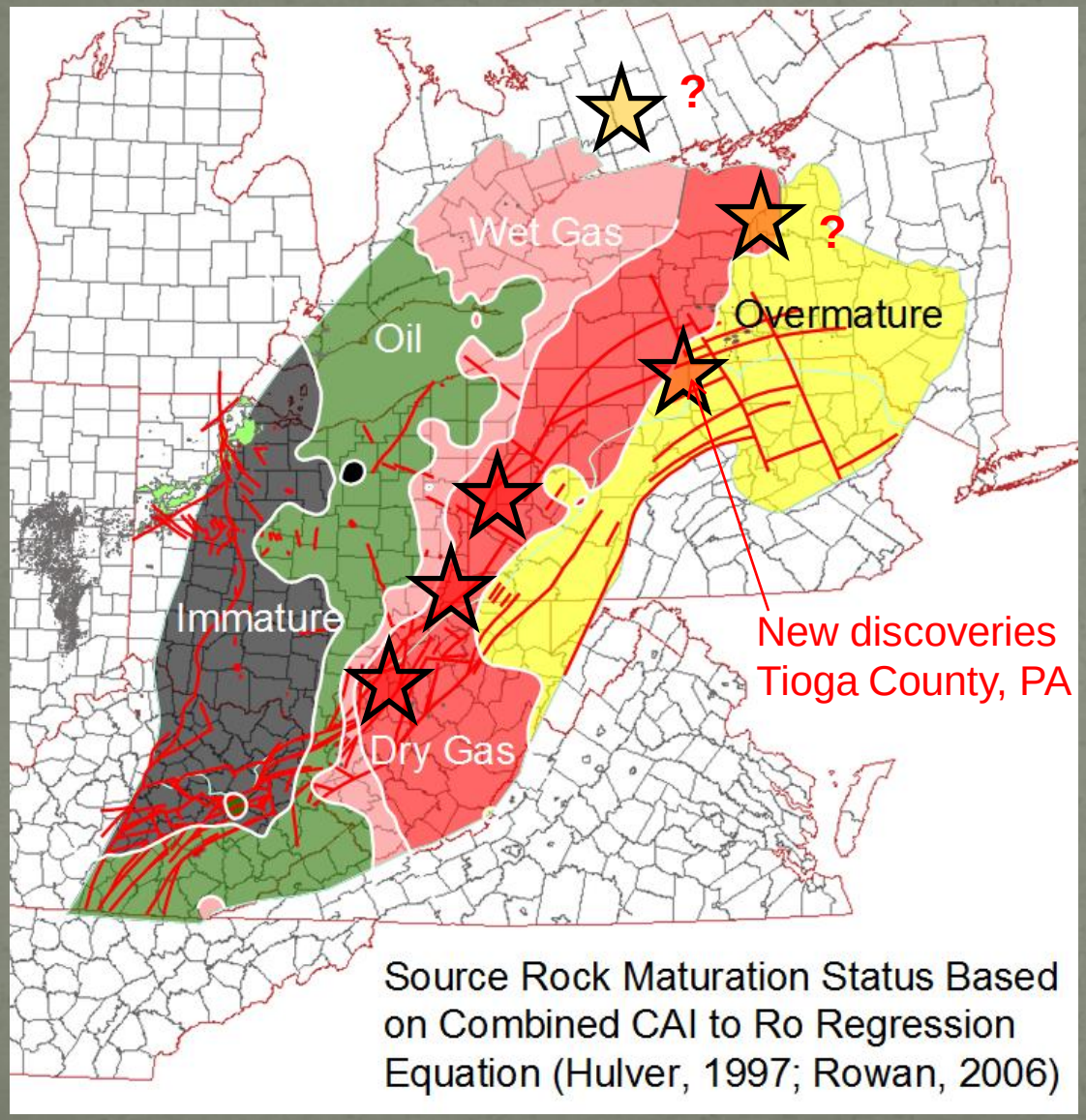






Regional cross sections showing facies change from organic rich Utica shale to non organic seal and IP's.

Regional Utica Thermal Maturity Patterns



Source: 2003 RPSEA

Two Utica Point Pleasant core areas in OH, WV, and PA

Major recent Utica Point Pleasant discovery in Tioga County, PA.

Possible extensions into NY?

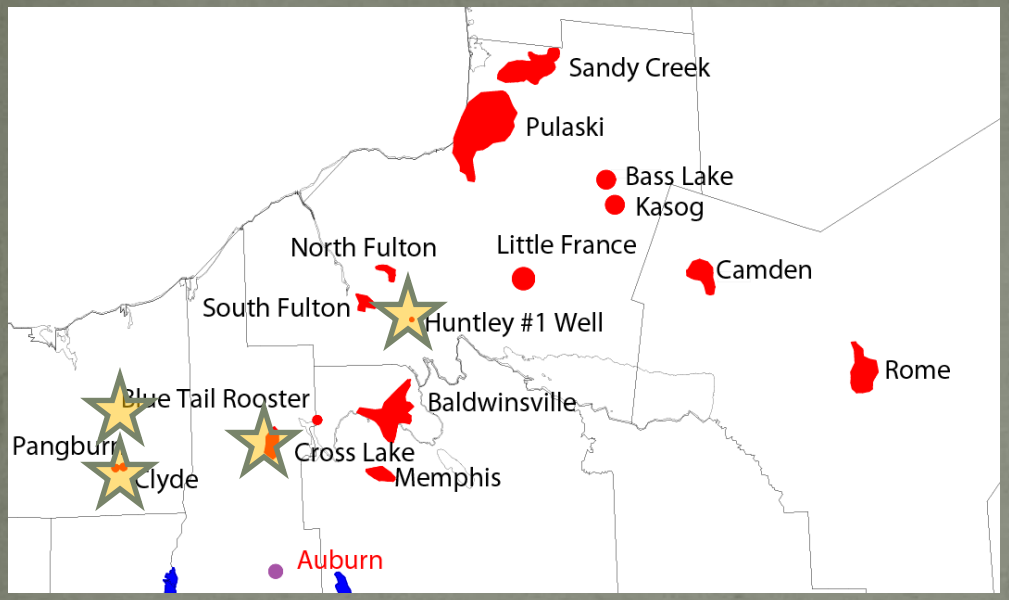
Southwest edge of play also testing !

What about Trenton self sourced gas plays in NY?

Ontario Collingwood shale play?

Extensions of NY Trenton gas play?

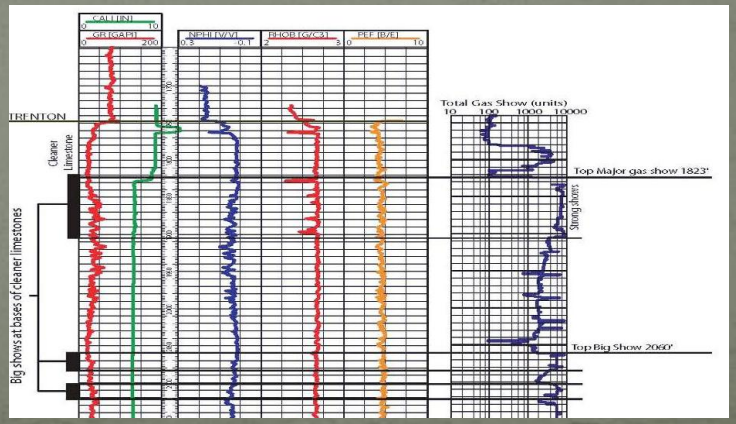
Shallow Trenton Gas Fields – Modern Development Lake Ontario Shoreline



Source: 2005 NYSERDA Nyahay, Bray, Schultz, Smith

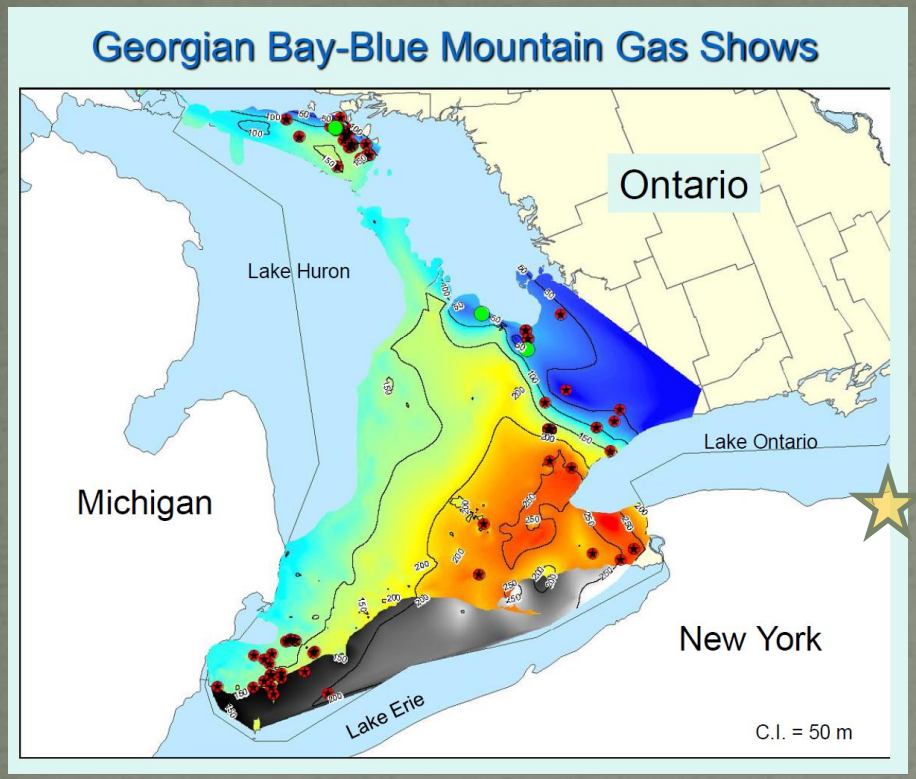
- 1880's marked start of shallow gas industry in NY.
- Wells were shallow 600' to 2,600' in the Trenton.
- Flow rates and pressures initially high but were low volume producers.
- Early recognized as a shale gas play.
- 1960's Blue Tail Rooster Field NY
- 2003 Several operators active in over pressure play.

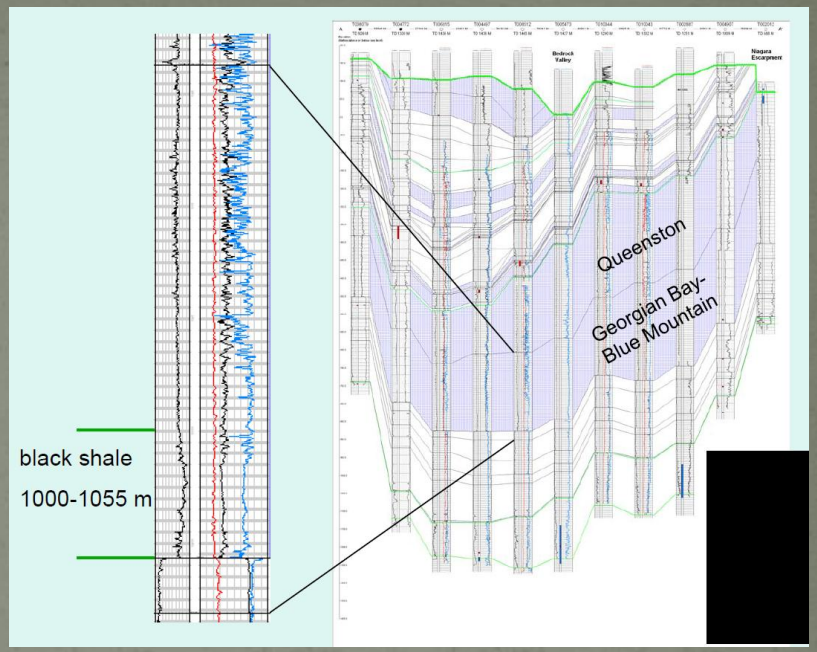
Source: Zagorski 2007



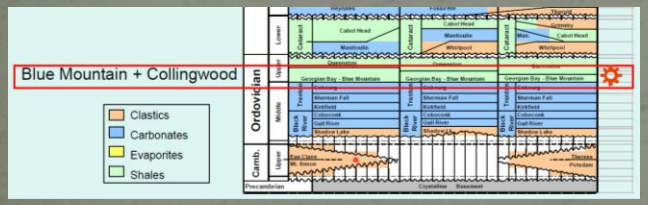
Source: 2005 NYSERDA Nyahay, Bray, Schultz, Smith

Ontario Ordovician Shale Plays





Source: 2011 OPI Conference – Carter, Fortner, Otis



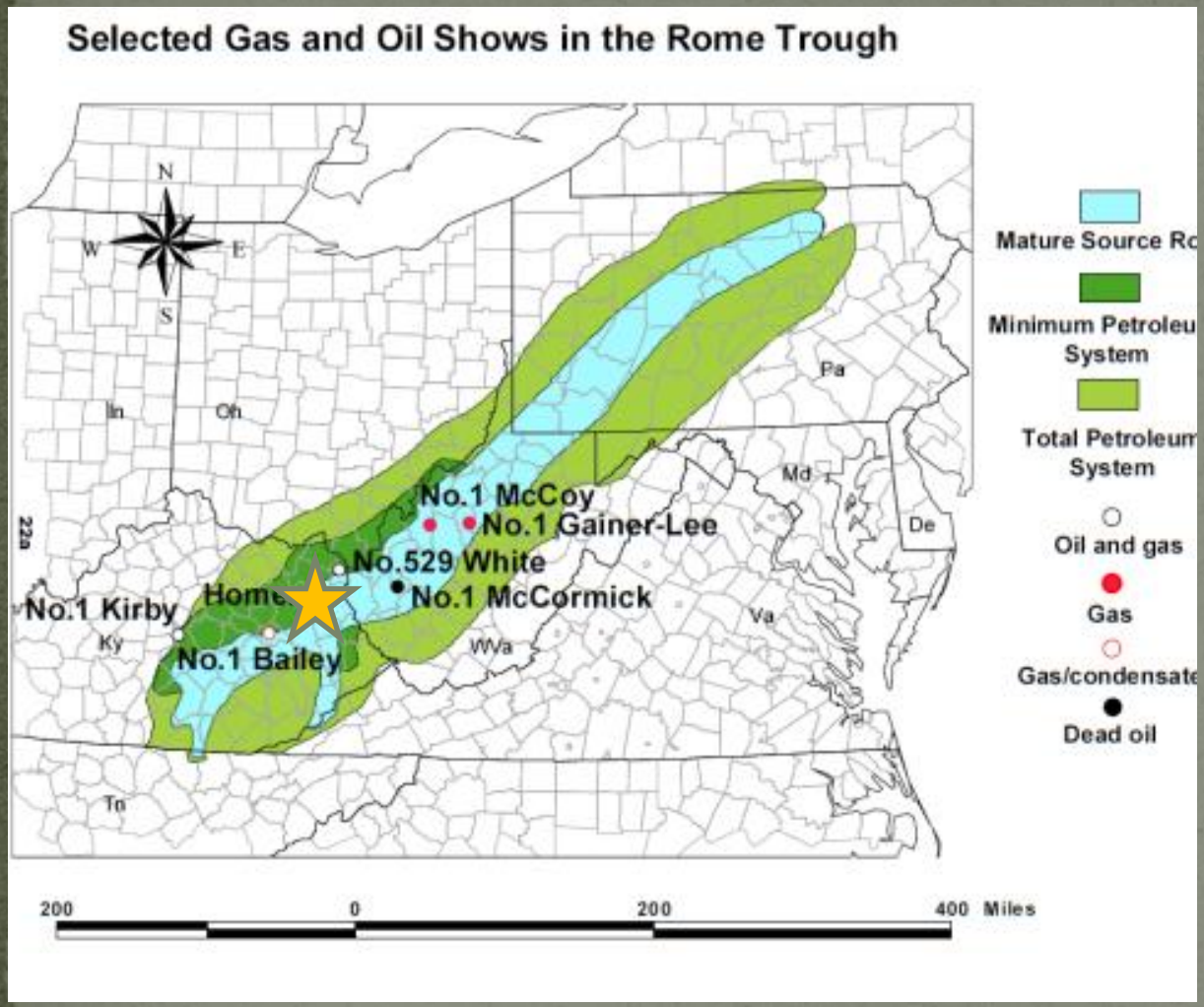
Significant potential in Georgian Bay, Blue Mountain and Collingwood Shale intervals.

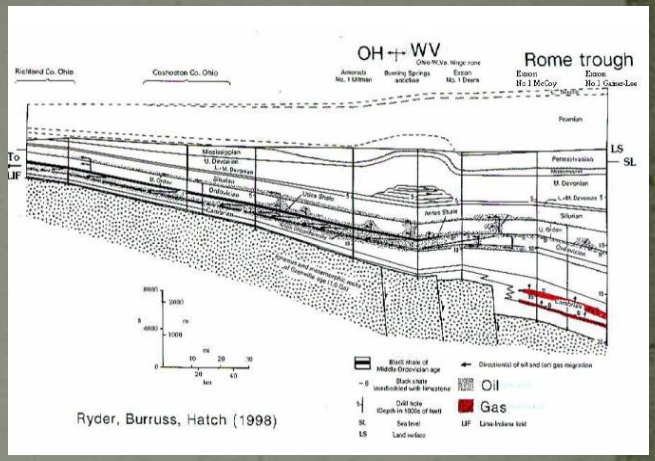
Thick organic rich sequences and TOC contents of 1% to 11%.

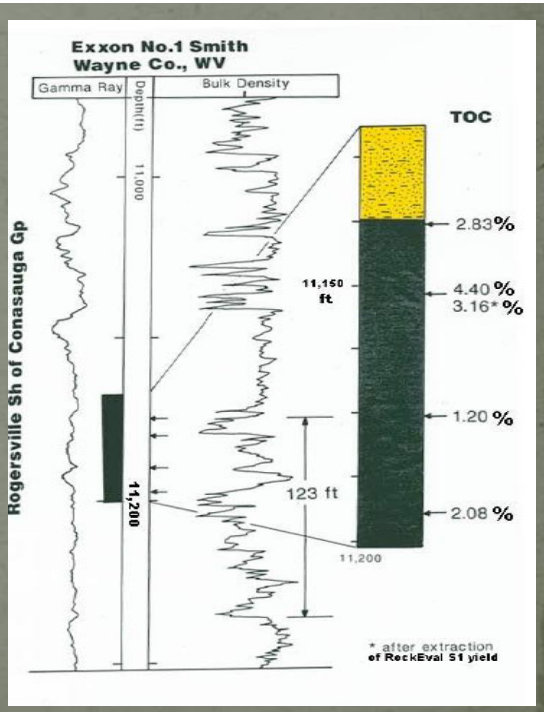
Depths to best targets are in the 1000 meter range.

Lots of studies completed recently but no large scale testing or horizontal completion as yet.

Cambrian Conasauga/Rogersville Shale Play



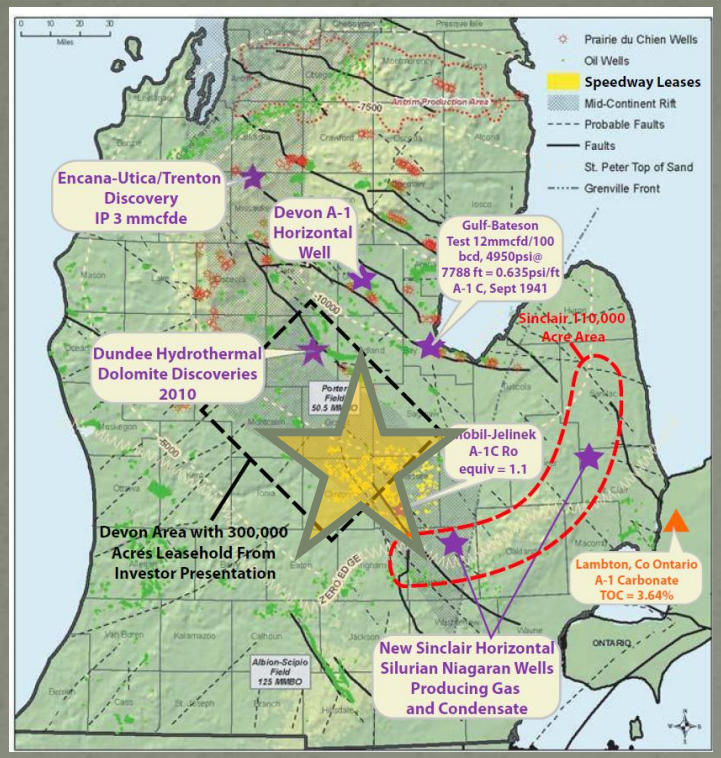




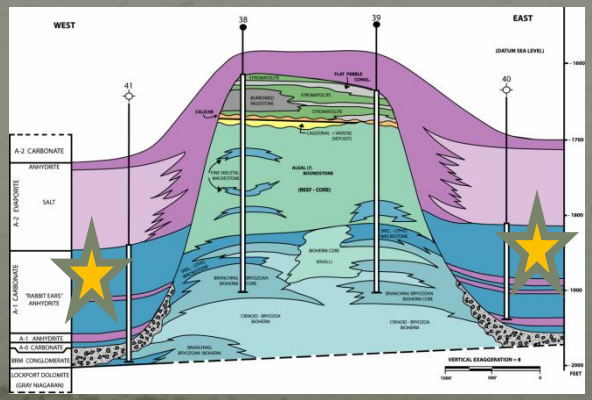
Source: USGS Ryder 2005

Testing of this play underway in KY and WV!

Michigan Silurian A1 Carbonate Resource Play



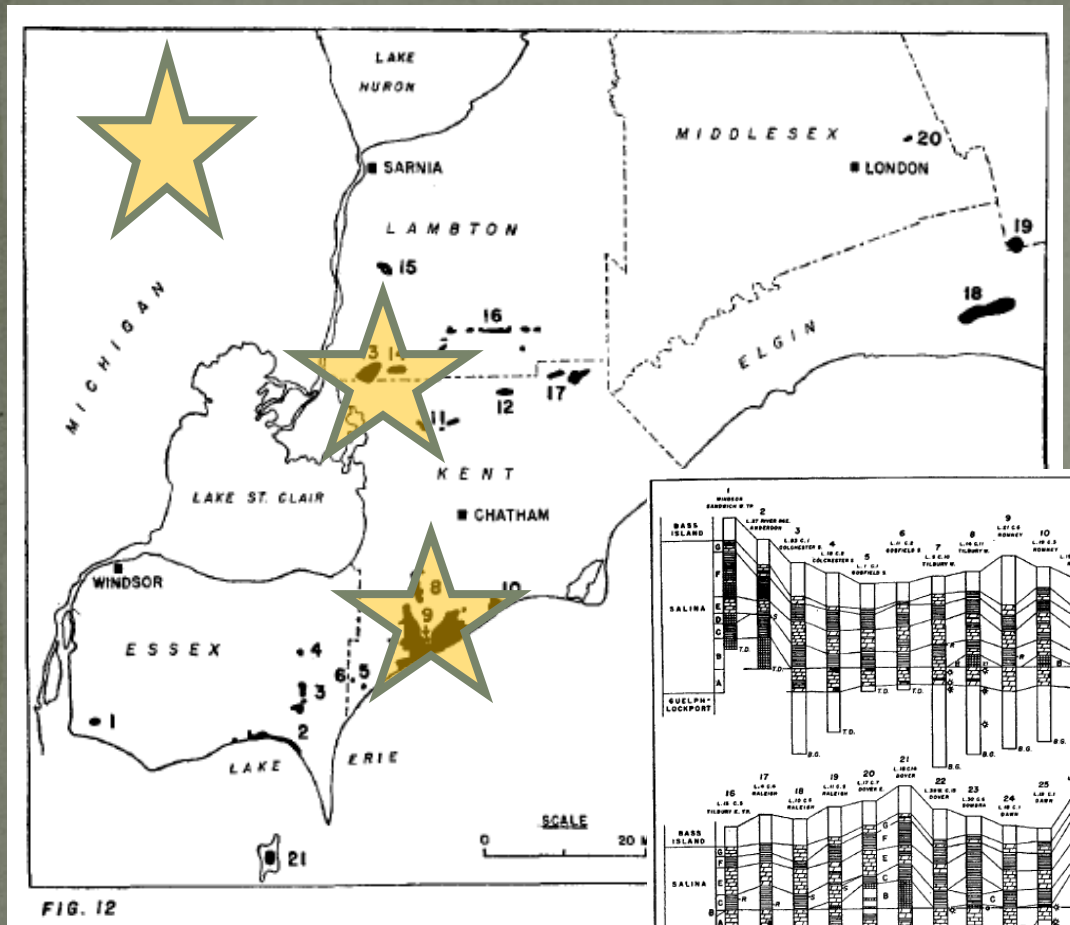
Source:2012 Gognat – Speedway Prospect Flyer



Source: Gill 1973

- Resource play developing in MI targeting inter-reef, organic rich intervals.
- Documented high TOC content.
- Significant overpressure.
- H2S hazards in portions of play.
- Basin wide play, significant extent.
- Lots of exploration interest in 2011 through 2013.
- Still lots of technical challenges to overcome.

Ontario Salina Production and Potential Source Rock Play



Source: 1949 Roliff - AAPG

Ontario has long history of Salina/Guelph production.

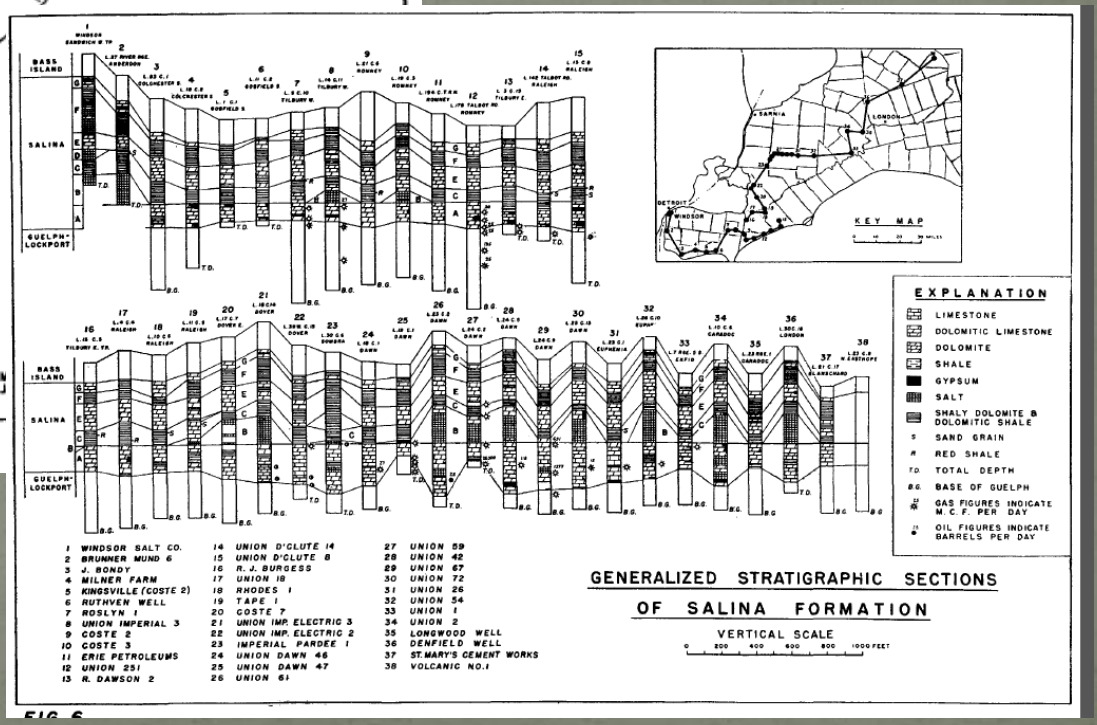
Fletcher and West Becher Pools.

Similar source rock potential and play may be present in Ontario.

Documented production/shows from interval.

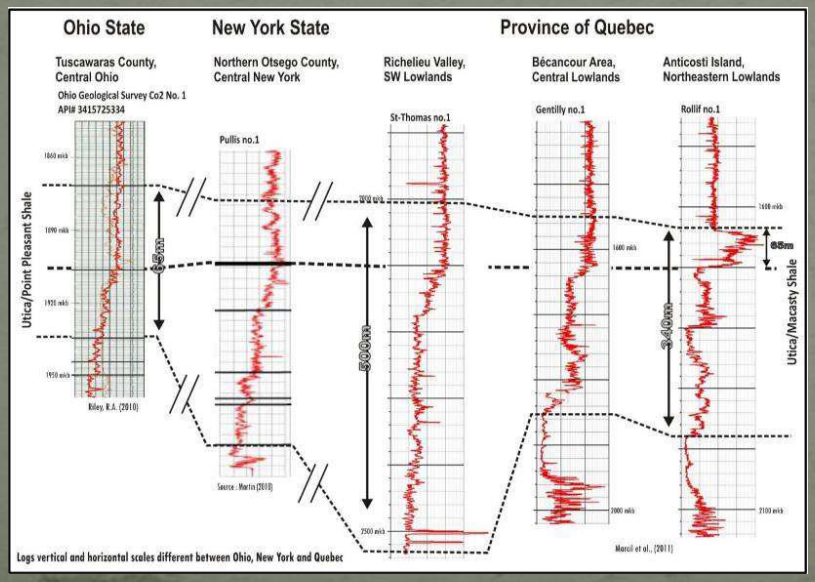
High TOC content, up to 3.5%.

Significant regional extent.



Macasty Shale Play - Anticosti Island Quebec

Source: AAPG Marcil 2013



Source: Marcil 2013

Initial testing by Arco in 1970.

Second exploration phase in 1990's targeted HTD plays.

Current focus is on the organic rich Macasty Shale.

Unit equivalent to Ohio Point Pleasant target.

In light oil condensate window.

Recent resource assessment for prospect shows 12.2 Billion BOE covering 233,275 acres.

THANK YOU!!! – THAT IS A LOT OF HISTORY AND POTENTIAL!!!!