Topical Report: DE-FC26-04NT15513

Phase I (Year 1) Summary of Research – Establishing the Relationship between Fracture-Related Dolomite and Primary Rock Fabric on the Distribution of Reservoirs in the Michigan Basin

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ABSTRACT

This topical report covers the first 12 months of the subject 3-year grant, evaluating the relationship between fracture-related dolomite and dolomite constrained by primary rock fabric in the 3 most prolific reservoir intervals in the Michigan Basin (Ordovician Trenton-Black River Formations; Silurian Niagara Group; and the Devonian Dundee Formation). Phase I tasks, including **Developing a Reservoir Catalog** for selected dolomite reservoirs in the Michigan Basin, **Characterization of Dolomite Reservoirs** in Representative Fields and **Technology Transfer** have all been initiated and progress is consistent with our original scheduling.

The development of a reservoir catalog for the 3 subject formations in the Michigan Basin has been a primary focus of our efforts during Phase I. As part of this effort, we currently have scanned some 13,000 wireline logs, and compiled in excess of 940 key references and 275 reprints that cover reservoir aspects of the 3 intervals in the Michigan Basin. A summary evaluation of the data in these publications is currently ongoing, with the Silurian Niagara Group being handled as a first priority. In addition, full production and reservoir parameter data bases obtained from available data sources have been developed for the 3 intervals in Excel and Microsoft Access data bases. We currently have an excess of 25 million cells of data for wells in the Basin. All Task 2 objectives are on time and on target for Phase I per our original proposal.

Our mapping efforts to date, which have focused in large part on the Devonian Dundee Formation, have important implications for both new exploration plays and improved enhanced recovery methods in the Dundee "play" in Michigan – i.e. the interpreted fracture-related dolomitization control on the distribution of hydrocarbon reservoirs. In an exploration context, high-resolution structure mapping using quality-controlled well data should provide leads to convergence zones of fault/fracture trends that are not necessarily related to structural elevation. Further work in Phase II will be focused on delineating the relative contribution to fracture-only dolomitization to that which occurs in conjunction with primary facies and/or sequence stratigraphic framework.

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EXECUTIVE SUMMARY

This topical report covers the first 12 months of the subject 3-year grant, evaluating the relationship between fracture-related dolomite and dolomite constrained by primary rock fabric in the 3 most prolific reservoir intervals in the Michigan Basin (Ordovician Trenton-Black River Formations; Silurian Niagara Group; and the Devonian Dundee Formation). Phase I tasks, including **Developing a Reservoir Catalog** for selected dolomite reservoirs in the Michigan Basin (Tasks 2.1, 2.2, and 2.3), **Characterization of Dolomite Reservoirs** in Representative Fields (Tasks 3.1, 3.2, 3.3, 3.4 and 3.5) and **Technology Transfer** (Task 5) have all been initiated and progress is consistent with our original scheduling. The delay in receiving the remaining 58% of the Phase I funding until March 22, 2005, has resulted in only minor delays, mainly related to purchase of capital equipment and commitment of graduate student research assistants, both of which are currently on track as discussed in the body of the report below.

The development of a reservoir catalog for the 3 subject formations in the Michigan Basin has been a primary focus of our efforts during Phase I (Task 2). As part of this effort, we currently have scanned some 13,000 wireline logs, and compiled in excess of 940 key references and 275 reprints that cover reservoir aspects of the 3 intervals in the Michigan Basin. Summary evaluations of the data in these publications is currently ongoing, with the Silurian Niagara Group being handled as a first priority because of the large numbers of publications devoted to this interval (Subtask 2.1). In addition, full production and reservoir parameter data bases obtained from available data sources have been developed for the 3 intervals in Excel and Microsoft Access data bases with an excess of 25 million cells of data, (Subtask 2.2). For the geologic mapping of structure and folds (Subtask 2.3), we have prioritized the Devonian Dundee, in part because of the limited data available for this Formation, but also because we have ready access to abundant core data. All Task 2 objectives are on time and on target for Phase I per our original proposal.

The characterization of select dolomite reservoirs (Task 3) has only recently started because the selection of samples is dependent upon results of Subtask 2.0. We are currently matching prioritized fields being identified in Task 2 with availability of rock data for interpretation of depositional environments, fracture density and distribution as well as thin section, geochemical, and petrophysical analyses. In addition, we have currently digitized over three thousand wireline logs covering the subject intervals. Task 3 objectives are on time and target for Phase I as per our original proposal.

Task 4 is in the development/planning phase as per our original proposal. Most of the effort on this task will necessarily follow results of Phase I (results from Tasks 2 and 3).

Technology transfer efforts (Task 5) have begun with formal presentations at 4 professional venues around Michigan and at the Eastern Section AAPG Meeting in Morgantown, WV, as well as ongoing advertisement of the project's scope, anticipated results and DOE as the funding agency on the WMU Department of Geosciences web site. As one indication of the level of significance this project is being accorded in the professional community, one of our papers was selected for the Vincent E. Nelson Memorial Best Poster Award for the AAPG Eastern Section meeting this past September.

A dedicated project web site linked both to the Department of Geosciences and the WMU Michigan Basin Core Research Laboratory is currently being developed, and general information

on the scope and goals of the project are currently available on the WMU Department of Geosciences website.

Our mapping efforts to date, which have focused in large part on the Devonian Dundee Formation, have important implications for both new exploration plays and improved enhanced recovery methods in the Dundee "play" in Michigan – i.e. the interpreted fracture-related dolomitization control on the distribution of hydrocarbon reservoirs. In an exploration context, high-resolution structure mapping using quality-controlled well data should provide leads to convergence zones of fault/fracture trends that are not necessarily related to structural elevation. Acquisition of high-resolution seismic data in areas with prospective structural grain may provide decreased risk for fractured Dundee exploration drilling.

Application of fracture models to reservoir characterization in secondary and tertiary recovery projects in existing fractured Dundee fields may result in substantial additional recovery from fields that typically had low (<30%) primary recovery factors. Careful consideration of fracture orientations and water coning problems should decrease risk in enhanced recovery activities.

Undoubtedly more complex, hybrid reservoir types exist in dolomitized lower Dundee/Reed City Member lithofacies in the central basin. This is anticipated as a result of complex, early fluid flow through primary limestone pore conduits within a reflux system, in addition to fracture-generated pathways in fault/fracture convergence zones. Much additional work is necessary to understand Reed City Member dolomitization processes in Michigan and implications for petroleum geology and is a primary goal of Phase II efforts.

Summary of Phase I Progress by Task

Task 2.0 – Development of a Reservoir Catalog for selected dolomite reservoirs in the Michigan Basin

1. **Wireline Log Scanning** – to date we have scanned about 13,000 wireline logs. These are digital raster images captured by using the Neuralog Scanner. Each image is a TIFF type image, scanned at 200 dpi resolution. These images can be used directly in Petra software for creating cross-sections and for stratigraphic correlation. They can also be pasted into text files as illustrations or used in Powerpoint presentations or on posters. These images can also be digitized into LAS files using the Neuralog software.

2. **Digital Conventional Porosity and Permeability Core Analyses** – students have been key punching core analysis data from paper copies into Excel spreadsheets to supplement our current digital databases. To date they have completed an additional 122 wells from four northern Michigan counties across the Niagaran Reef trend. This data includes the depth of the analyzed core sample, conventional air permeability and helium porosimetry, oil and water saturations, descriptive lithology and (when available) gas chromatographic analyses of C-1 through C-5 on selected footages.

3. **Brine Chemistry Data** – Students have key-punched a paper data set from Dow Chemical containing brine analyses from the Michigan Basin. This data contains 218 analyses from numerous formations throughout the state and supplements our current digital data base. These have been entered into an Excel spreadsheet and added to a previous data set of 165 wells. To give a reasonably comprehensive data set of 383 wells. Data includes well location information, depth of sample, total dissolved solids (salinity), major elements, some trace elements and some temperature data.

4. **Dolomitized intervals in wells of Albion/Scipio Field** – An Excel spreadsheet has been created for all wells in the Albion/Scipio Field. This is the largest field in Michigan and

the largest Trenton-Black River Field in our study. The field contains 746 wells. The data set includes well location information and footage intervals in the Trenton and Black River formations that are dolomitized. This data will be used in concert with other databases to define the distribution of the Albion Scipio reservoir and construct a three-dimensional model of the reservoir. It will also be useful in selecting wells to analyze that might have core or cuttings. The dolomitized intervals were identified from drilling records for each well.

5. **Organizing and compiling other large digital datasets** – Numerous digital datasets for Michigan oil and gas wells are being combined into a single complete dataset (we currently have >25 million cells of data) for use in this project. An example of the parameters included are as follows:

    a. **Cored wells** – this is a listing of all known cored wells from Michigan. This list is compiled from private and public sources. It includes well location information, cored interval, cored formations, storage location of the core (if known), and analyses performed on the core (e.g. P&P).

    b. **Thin sections** – well name, footage interval, formation and repository location of thin sections.

    c. **Core Analyses** – conventional or special core analyses with footage analyzed and core properties (usually P&P) as reported in item #2 above.

    d. **Drill cutting samples** – well name and location along with depths and sample increment. There is also a database with numerous chromatographic analyses of bulk cuttings. Data includes abundance of C-5 though C-26 derived from solvent extraction on cuttings samples.

    e. **Engineering parameters** – lists of selected parameters and data including: bottom hole pressure, gas chemistry, and oil/gas ratio.

f. **Mudlogs** – contains lithologic descriptions, gas log and drilling comments.

g. **Wireline logs** – catalog of all logs run in Michigan wells, list of those in WMU collection, list of scanned images, list of LAS digital logs.

6. **Compiling exhaustive bibliography and reference reprint collection** – Using Endnotes software and extensive database of geologic and engineering references has been compiled and entered into the Endnotes software system.

Subtask 2.1 We currently have 941 references compiled and entered into an Endnote database on reservoirs aspects of dolomite. Of these, 348 are specifically on the Michigan Basin reservoirs in the zones of interest. The remaining 593 are on various aspects of dolomitization and dolomite reservoirs that may have application to our project goals. We will continue to add to the database and the collection of reprints.

We are on schedule per our original proposal whereby the majority of Subtask 2.1 has been completed during Phase I. Additional work will continue in Phase II and will be finalized in Phase III.

Subtask 2.2 Individual producing unit data bases have been constructed in Microsoft Access and Excel that include fields, numbers of wells, oil and gas production, brine production, active and abandoned wells. Currently we have over 25 million data points in various categories including well location coordinates and ID, TD, IP, Salinity and Water Chemistry, Production History, Core and Perforation locations, Formation tops, and results of various core analyses. Additional engineering parameters including porosity, permeability, derived water saturations and type/style of dolomite are still being added, and will continue to be added in Phase II and III to the 3 databases.

Production summaries and curves (see Appendix 1 for an example) have been created for 44 fields in the Trenton/Black River, 1151 fields in the Niagaran, and 141 fields in the Devonian. These data are currently being analyzed in relationship to the distribution of mapped fracture areas in the basin, with our initial focus on the Devonian as mentioned previously. These results are being correlated to fields with core data and petrophysical analyses to facilitate selection of samples for further petrographic and geochemical analysis for dolomite genesis and reservoir quality.

We are on schedule per our original proposal whereby the majority of Subtask 2.2 has been completed during Phase I with additional work continuing into Phase II and finalizing in Phase III.

- <u>Subtask 2.3</u>

Methodology and Objectives

In order to investigate the geological origins and controls on the occurrence of dolomite reservoirs in the Devonian Dundee Formation in Michigan we compiled available, digital subsurface geological data (mostly from the Michigan Department of Environmental Quality, Geological Survey Division, MDEQ-GSD) including formation tops, wire-line logs, and driller's reports. Where appropriate we compiled these data into tabular spatial databases. These spatial databases were used to construct Geographic Information Systems files (both ArcGIS and Petra software), maps and cross sections of important geological properties in the Dundee including the spatial distribution of dolomite versus limestone in the Dundee Formation relative to structural features and oil field occurrences in the Michigan Basin. Modern wire-line logs in digital format from over 400 wells were analyzed. Quality controlled Dundee Formation tops from a more than 25,000 well database (originating from J. R. Wood, MTU Subsurface Visualization Lab) were used in the structural mapping.

The current availability of large institutional digital subsurface databases, modern digital well logs, readily accessible computational power and appropriate software provides the opportunity to evaluate correlations amongst general structural and lithologic trends in the Dundee from a wide range of data sources. A limited number of modern litho-density well logs basin wide provides the most important source of information available for investigation of lithology in the Dundee Formation relative to spatial location and structural features in the Michigan basin subsurface.

Implications for Petroleum Geology in Michigan and other U.S. Hydrocarbon Basins

Our analyses to date have important implications for both new exploration plays and improved enhanced recovery methods in the Dundee Formation "play" in Michigan – i.e. on the basis of interpreted fracture-related dolomitization control on the distribution of hydrocarbon reservoirs. In an exploration context high-resolution structure mapping using quality controlled well data should provide leads to convergence zones of fault/fracture trends not necessarily related to structural elevation. High-resolution seismic data acquisition in areas with prospective structural grain may provide decreased risk for fractured Dundee exploration drilling.

Application of fracture models to reservoir characterization in secondary and tertiary recovery projects in existing fractured Dundee fields, may result in substantial additional recovery from fields that typically had low (<30%) primary recovery factors. Careful consideration of fracture orientations and water coning problems should decrease risk in enhanced recovery activities.

Undoubtedly more complex, hybrid reservoir types exist in dolomitized lower Dundee/Reed City Member lithofacies in the central basin as a result of complex, early fluid flow through primary limestone porosity conduits in a reflux system in addition to fracture generated pathways in fault/fracture convergence zones. Much additional work is necessary to understand Reed City Member dolomitization processes in Michigan and implications for petroleum geology.

Subtask 2.3 is on schedule per our original proposal timeline, and will continue as stated throughout Phases II and III.

Task 3.0 – Characterization of Dolomite Reservoirs in Representative Fields

- Subtask 3.0 will be a primary focus of Phase II and is dependent upon results of Subtask 2.0. We are currently matching prioritized fields being identified in Task 2 with availability of rock data for interpretation of depositional environments, fracture density and distribution as well as thin section, geochemical, and petrophysical analyses. To date we have digitized in excess of 3,500 wireline logs in the subject intervals.

Subtask 3.0 is on schedule to be mostly completed by the end of Phase II or early in Phase III. The potential for a bit more carryover into Phase III exists because of the 6 month delay in obtaining the full Phase I budget, and therefore selecting the sample intervals, calibrating the new equipment for Cathodoluminescence, calibrating the fluid inclusion equipment etc.. Assuming we receive the full budget for Phase II in the near future, we not anticipate this to adversely impact either the timing of, or content of the project deliverables in any way.

Task 4.0 – Development of Geological Models and Assessment of Application Potential

- As indicated in the original proposal, Task 4 will not really begin until Phase II as this is dependent upon results from Tasks 2 and 3.

Task 5.0 – Technology Transfer

- A dedicated project website linked to the WMU Michigan Basin Core Laboratory and Department of Geosciences is currently being developed. At the present time, a technical overview of the project is linked to the WMU Department of Geosciences web page (http://www.geology.wmich.edu/Dolomite-Michigan-Basin.htm) An overview of the project and DOE's support was printed in the Kalamazoo Gazette, and Detroit News – links to these articles are also included on the WMU Geoscience Department's Website: (http://www.geology.wmich.edu/default.htm).
- Dr. Grammer has given formal (invited) presentations discussing the project to the Michigan Oil and Gas Association (MOGA) on April 21, 2005, the Michigan Basin Geological Society along with Dr. Gillespie (May 18, 2005), the State of Michigan Geological Survey, Department of Natural Resources and the Department of Environmental Quality (May 24, 2005), and at the regional PTTC technology workshop on October 20, 2005. The project team (Drs. Grammer, Barnes, Harrison and Gillespie, along with students Tony Sandomierski and Audrey Ritter) displayed the project goals and approaches at this meeting as well. In addition, Drs. Grammer and Harrison had a display booth at the April Michigan

Oil and Gas Association (MOGA) meeting with details of the project available to the attendees.

- We presented some initial results at the Eastern Section of AAPG in Morgantown, WV in September (see Appendix 2). The presentations included some initial results of our mapping efforts in the Dundee ("Oil Field Structural Mapping and the Distribution of Dolomite in the Dundee Formation in Michigan", Barnes, Grammer, Harrison, Gillespie, Stewart, Wahr, and Kirschner), as well as an initial reservoir characterization of Niagaran reefs ("Evaluating Controls on the Formation and Reservoir Architecture of Niagaran Pinnacle Reefs (Silurian) in the Michigan Basin: A Sequence Stratigraphic Approach", Sandomierski, Grammer and Harrison).
- The paper by Sandomierski et al. was selected for the Vincent E. Nelson Memorial Best Poster Award for the AAPG Eastern Section meeting.

Graduate Students: As stated earlier, because of the delay in the receipt of the full budget award, we were not able to commit to students for the academic year 2004/2005. However, with DOE approval of our request for carryover of Phase I student support into Phase II (W. Mundorf, April 19, 2005), we now have two graduate students that started this Fall (September, 2005) who will be fully supported research assistants working on the project for their MS degrees. The specific areas/topics of their individual research are not fully defined at this point, other than being an integral part of the overall project. Early discussions indicate that Ms. Ritter will likely be working on stratigraphic relationships of reservoir quality dolomite and that Ms. Crisp will be working on the petrophysical characterization of the different phases of dolomite and their predictability on wireline logs and/or seismic. In addition, Tony Sandomierski (M.S. student) has been working on aspects of Niagaran Reefs that began before this project was funded but that are being included into our results and data sets. It is also possible that we will also be bringing in an additional 1-2 graduate students next year to work on various aspects of the project.

Summary highlights of the two new students:

- <u>Audrey Ritter</u> – Ms. Ritter is a WMU Lee Honors College graduate who did a senior honors thesis with Dr. Grammer studying Carboniferous Phylloid Algal mounds in the

Paradox Basin of Utah. Audrey has received grants and awards from the Lee Honors College at WMU, the College of Arts and Sciences, and the Department of Geosciences for her undergraduate research work. She has also received grants from the Michigan Basin Geological Society and the Eastern Section of AAPG. She was the president of the WMU Student Chapter of AAPG in 2004/2005. Audrey has formally presented her research at the Michigan Basin Geological Society, the Eastern Section of AAPG, and at the National AAPG in Calgary in June. Audrey completed a summer internship with Equitable Resources in Pittsburgh, PA this past summer.

- Jessica Crisp – Ms. Crisp is also a graduate of WMU who has done undergraduate research on carbonate sand bodies with Dr. Grammer. Jessica has presented her research formally at the Michigan Basin Geological Society. Jessica was awarded a summer internship with NASA in 2004 under the Planetary Geology and Geophysics Undergraduate Research Program. Jessica worked on bedform formation and migration in the Planetary Aeolian Facility at Moffett Field, CA. She has been an officer in both the WMU Geology Club and the WMU AAPG Student Chapter.

Equipment purchased during Phase I:

- Cathodoluminescence Microscope – the CL microscope and digital image equipment is scheduled to be delivered by Luminoscope Corporation the week of November 14-18 (contact: Thomas Cunningham). Luminoscope has honored the original quote of $46,000 received in January 2004 while developing the proposal. This equipment will be at WMU and fully operational by the start of Phase II.
- Two high-end computer (PC) workstations).

DISCUSSION: PHASE I - INITIAL RESULTS FROM TASKS 2 AND 3

Controls on Dolomitization in the Middle Devonian Dundee Formation - Oil Field Scale Structure and the Distribution of Log-Based Dolomite Lithofacies:

Introduction

The Middle Devonian Dundee Formation (Figure 1) is a prolific oil and gas producer, initially discovered in 1927, with cumulative oil production to date in excess of 350 MMBOE from over 130 fields in the Michigan Basin (Figure 2). Exploration and production drilling in the Dundee in the 1920's through the 1940's was conducted prior to the advent of modern drilling technology or acquisition of quantitative reservoir characterization data. Furthermore, many Dundee wells were "top set"; that is, drilled to within a few feet of the top of the producing horizon and completed for production with little or no sampling or logging of reservoir rock types. Oil and gas production is known from both primary limestone and secondary dolomite reservoirs in the Dundee.

Limited modern logs and rare core from more recent drilling activity in the Dundee provide an incomplete picture of important reservoir lithofacies, their distribution, and geological origin in Michigan. Geological models for the origin of prolific oil producing dolomite reservoir facies, most common in the central Michigan basin, are of particular interest. A better understanding of the origin, regional distribution, and reservoir scale characteristics of this dolomite reservoir facies should have significant impact on continued exploration for novel and untested exploration targets, and increase the effectiveness of secondary and tertiary recovery operations in the Basin in the Dundee Formation.

On the basis of unpublished work by numerous petroleum geologists in Michigan during the Dundee boom years of the 1930' and 1940's and more recent work, petroleum production is thought to occur from at least three different reservoir lithofacies types (Knapp, pers. comm., Fig. 3a and b):

1) Sedimentary Facies-controlled ("early diagenetic") dolomite reservoirs, dominantly in the western third of the central basin such as in the Reed City Member (e.g. Reed City Field).

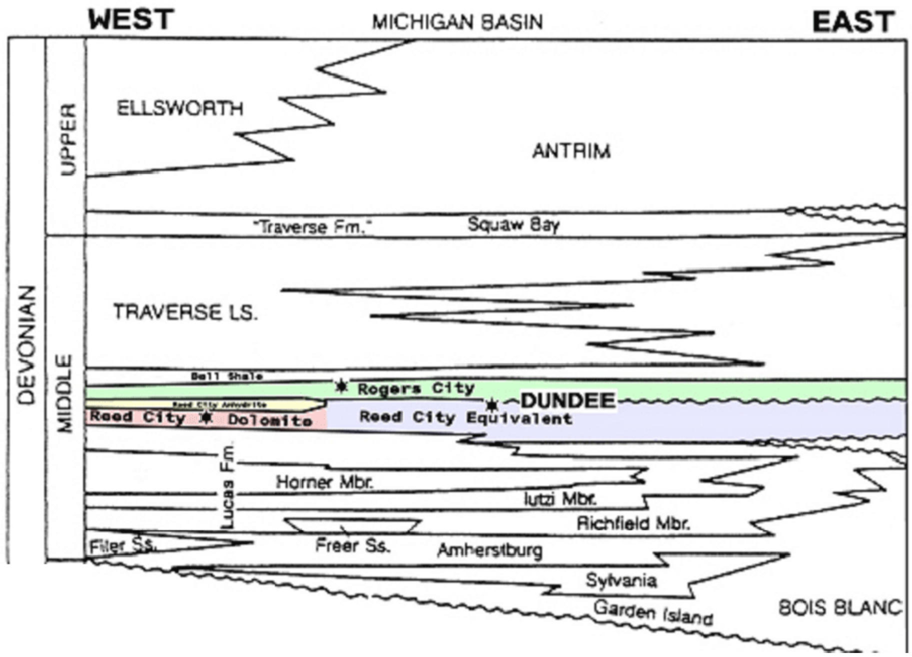


Figure 1. Devonian stratigraphy in the Michigan basin, from Gardener, 1971 (Drafted by Eric Taylor)

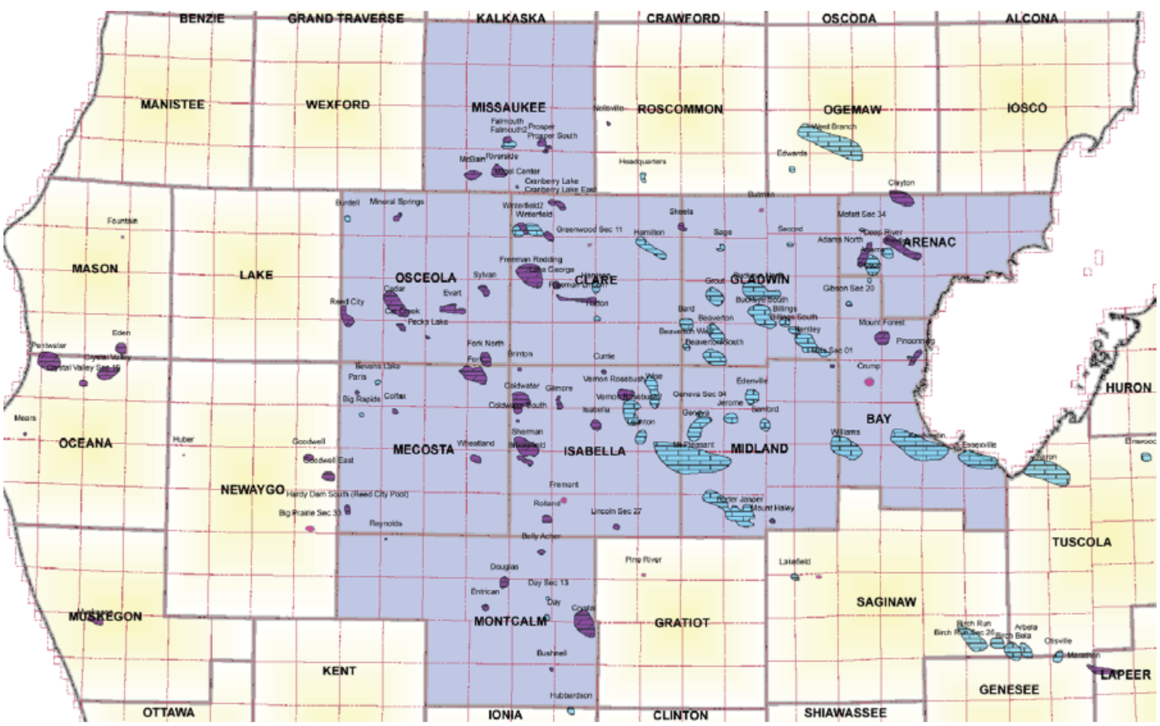


Figure 2. Dundee Formation fields in Michigan. Probable producing lithology indicated by dolomite and limestone symbols

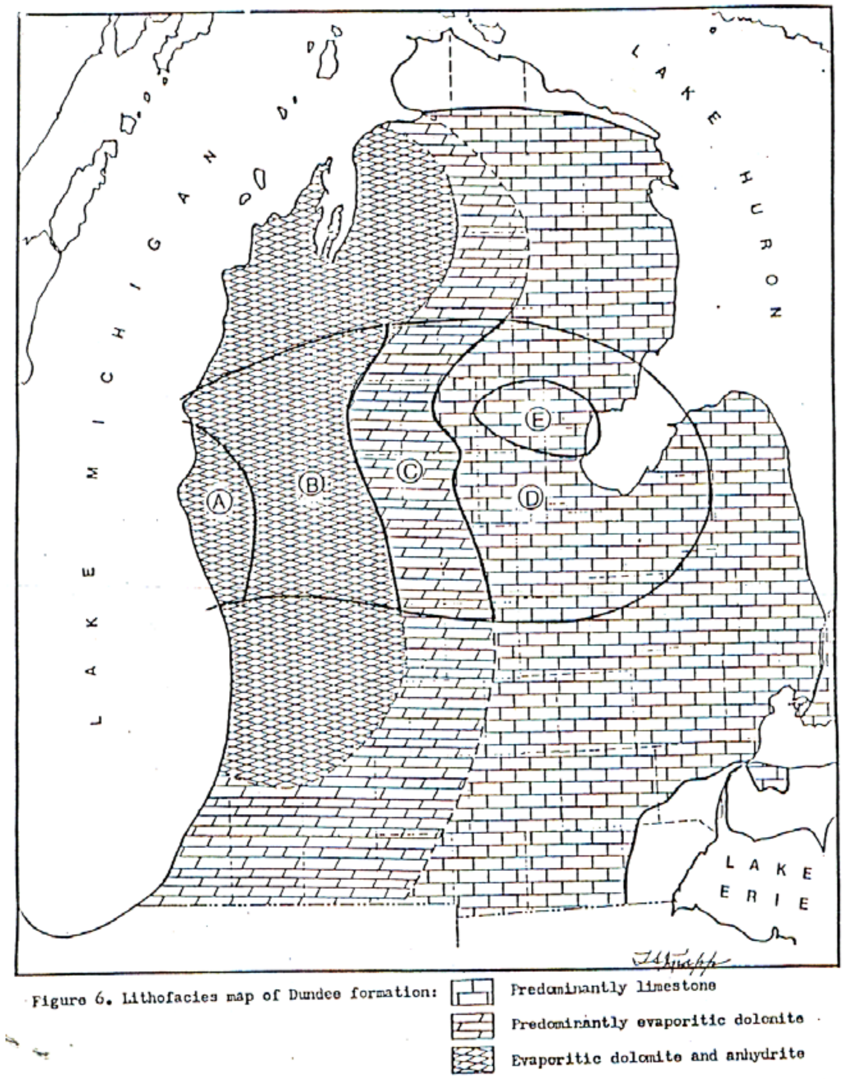


Figure 3a. Generalized lithofacies and spatial distribution of reservoir types in the Dundee Formation, from Tom Knapp, personal communication

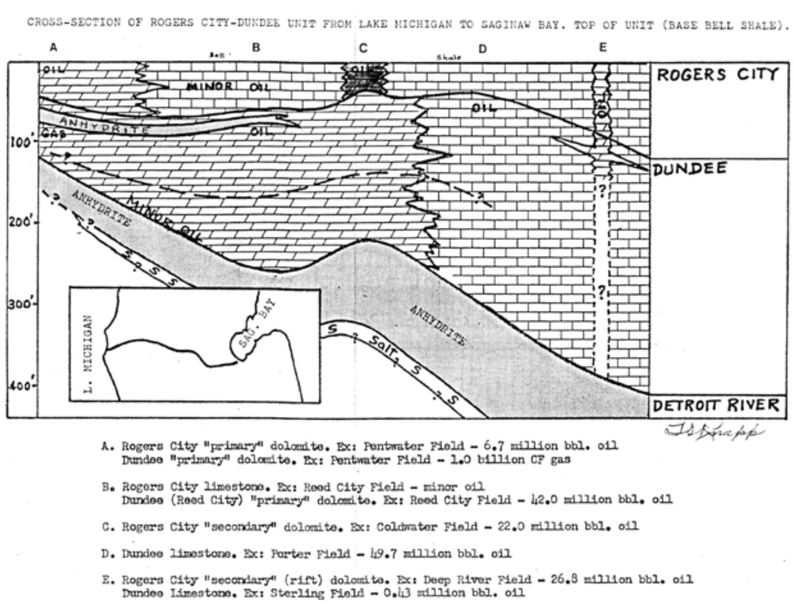


Figure 3b. Generalized lithofacies and spatial distribution of reservoir types from Tom Knapp, personal communication. "Dundee" unit refers to Reed City Member of this report.

2) Sedimentary Facies-controlled limestone reservoirs, mainly in the eastern third of the central basin in the Reed City "equivalent" Member (e.g. South Buckeye, Mt. Pleasant, and West Branch fields).

3) Dolomite reservoirs of controversial origin in the upper Dundee/Rogers City Member predominantly in the central basin (e.g. Vernon Field), but also noteworthy both to the far west (e.g. Pentwater field) and east (e.g. Deep River Field). Some fields of this type have been referred to as "dolomite chimneys" due to linear, fracture-related field geometry.

Geological Background - Dundee Formation

The Dundee Formation in the Michigan Basin consists of two subsurface members, the Reed City and overlying Rogers City members (Gardner, 1974, see Figure 1). A diverse lithologic assemblage of predominantly fossiliferous and grainy carbonate rocks of the Reed City member overlies dolomicrite, anhydrite and salt of the Lucas formation, deposited in sabhka, peritidal, and restricted lagoon environments (Gardner, 1974, Figure 1). The Reed City Member is most distinct in the western parts of the basin where it consists of restricted marine, peritidal facies, including a prominent anhydrite unit informally called the Reed City anhydrite near the top of the member. The primary depositional facies in the Reed City member basin-wide consists of a shallow marine shelf carbonate assemblage including, grainy carbonate, stromataporoid reef, and peritidal to supratidal/evaporitic facies that generally shoal upwards to the Rogers City contact (Gardner, 1974; Montgomery, 1986; Curren and Hurley, 1992, Montgomery, and others, 1998). More open marine limestone facies (Reed City “equivalent”) are predominant in the eastern basin, while more restricted, dolomitized and evaporite-bearing facies (Reed City Member) occur to the west (Gardner, 1974, Figure 4) suggesting that the Reed City was deposited on a carbonate ramp that transgressed the basin from east to west. Pervasive alteration of grainy and fossiliferous primary limestone facies to dolomite occurs in the Reed City member throughout most of the western parts of the Michigan Basin. The Reed City member comprises a complex primary facies mosaic that is not well known due to the lack of outcrop and subsurface core material in the basin.

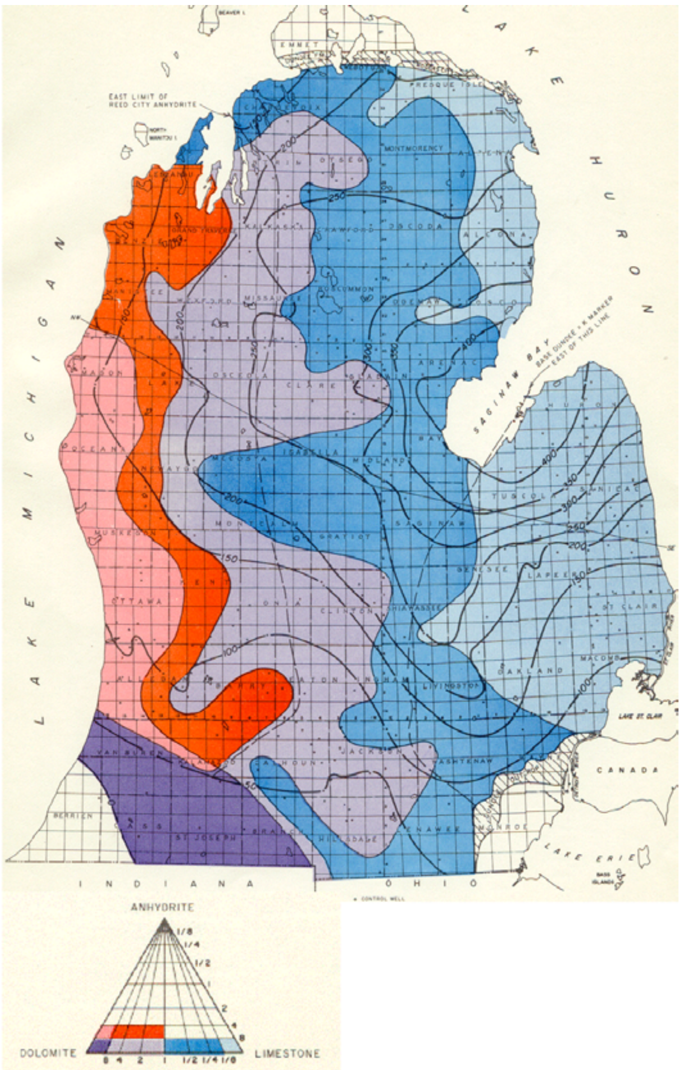


Figure 4. Dundee Formation (Reed City Member) lithofacies and isopach map from Gardner, 1974.

The Rogers City Member overlies various rock types of the Reed City Member at a generally sharp, probable marine flooding surface (as determined in core, Curran and Hurley, 1992) that marks an apparent rapid marine transgression. This contact is not easily recognized in logs, especially in the east, and its origin may vary throughout the basin. Primary depositional facies in the Rogers City, although incompletely known due to limited core, are generally lithologically homogeneous and consist of mostly open marine nodular lime wackestone to mudstone. Biostromal buildups and spatially-related fossiliferous grainstone-packstone deposits in the upper Reed City-Rogers City interval found in several oil fields in the eastern basin, suggest possible syn-depositional structural relief on the sea floor and resulting shoal water facies in some parts of the Michigan Basin during the transition from the upper Reed City equivalent to the Rogers City member (Montgomery, 1986).

Dolomite Reservoirs in the Dundee Formation

Some of the most productive (initial production (IP) of 2000-9000 BOPD) reservoirs in the Dundee are found in dolomite facies in the central and western parts of the basin. Some of the largest fields include the Reed City Field (42.9 MMBO); Deep River Field (27.2 MMBO); Coldwater Field (22.3 MMBO); Freeman-Redding Field (17 MMBO); and North Adams Field (9.5 MMBO). Dolomite reservoirs in the Reed City Member are thought by some basin geologists to originate as "early diagenetic" or "facies related" dolomite that is spatially related to the stratigraphic distribution of the Reed City Anhydrite (see Figure 3b and 4) and formed through seepage reflux mechanisms (Jones and Xiao, 2005, Figure 5). This is likely the case in several fields in the western basin (Reed City, most notably). Application of a seepage reflux model to the distribution of dolomite reservoirs in the central basin, however, is strongly dependant on an inferred pinch-out of the Rogers City Member over a proposed “shell bank” or shoal water bathymetric feature that existed in the central basin during the transition between Reed City and Rogers City time (Figure 6). A pinch out of the Rogers City member is interpreted to exist over this “shell bank”, and magnesium-rich saline fluids are thought to have migrated basin-ward and up-section, dolomitizing porous primary limestone facies in the Reed City Member that extended to the top of Dundee Formation at the base of the Bell Shale.

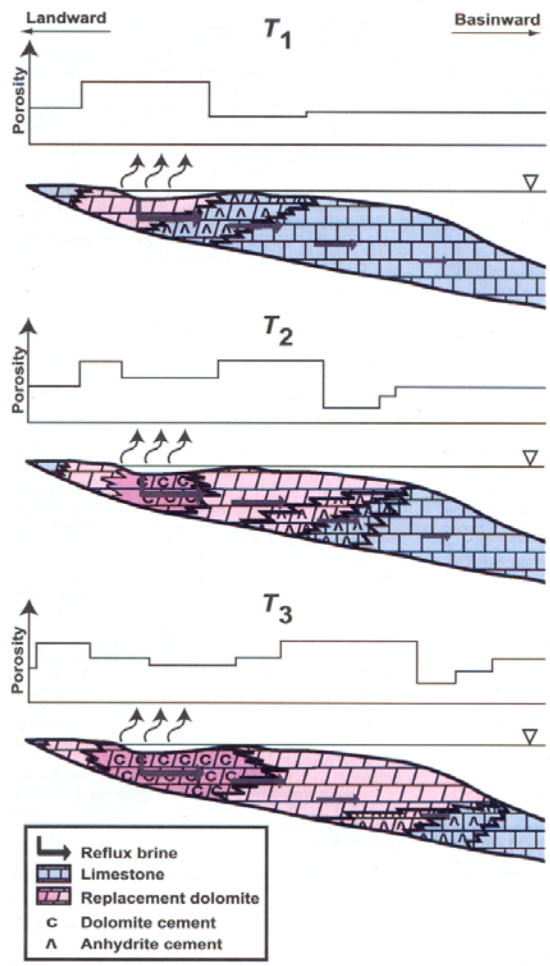


Figure 5. Model for lithofacies distribution in a reflux system, from Jones and Xiao, 2005.

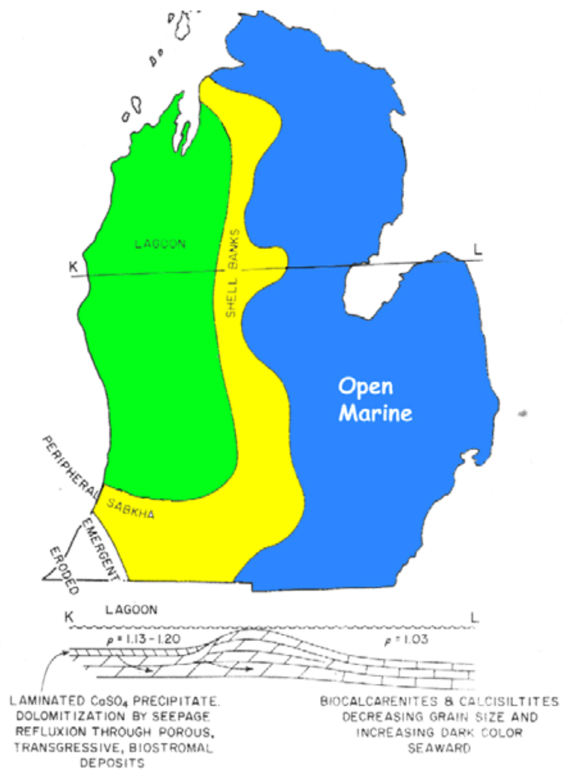


Figure 6. Paleogeographic map and cross section during regressive, Reed City member time, from Gardner, 1974. Note the inferred paleo-bathymetric high in the central basin that is interpreted by many basin geologists to be responsible for pinch-out of the overlying Reed City Member in this area. It is important to note, however, that this “interpretation” has not been substantiated in the literature but is more of a general impression in the basin.

An alternative model for dolomitization of the upper Dundee, Rogers City member in the central basin has been suggested as resulting from fracture-related mechanisms and hydrothermal alteration (see model by Strecker and others, 2005 after Boreen and Davis, 2001, Figure 7). This is a much more feasible hydrodynamic model for dolomitization in the central basin if the upper Dundee originally comprised Rogers City member limestone because primary porosity in this predominantly lime mudstone to wackestone unit would preclude flow of significant dolomitizing fluids through primary permeability conduits. It is a widespread industry perception that such fracture mechanisms are the probable origin of linear "dolomite chimney" fields in the eastern Michigan Basin (e.g. Deep River, Pinconning, and North Adams fields in Arenac and Bay counties, Wood and Harrison, 1999), although this inference is based primarily on anecdotal drillers reports, mud logs and the distinctive linear geometry of the developed fields.

The importance of distinguishing mechanisms for dolomitization in Dundee Formation reservoirs is fundamental to maximizing production of hydrocarbons from this interval. Regional flow systems that delivered dolomitizing fluids to the Dundee, eastward of the probable source of these fluids in the western basin, would result in dolomitized reservoirs that may have significant lateral continuity dependant mainly on the lateral continuity of facies controlled, primary fluid flow conduits. In sharp contrast is the abrupt lateral discontinuity that should exist between primary limestone and dolomite as a result of fracture-controlled delivery of hydrothermal dolomitizing fluids. These distinct mechanisms for dolomitization would result in fundamentally different timing of reservoir and trap development, oil migration pathways, and reservoir geometry relative to structural features.

Study Methodology and Objectives

In order to investigate the geological origins and controls on the occurrence of dolomite reservoirs in the Dundee Formation in Michigan, we compiled available digital subsurface geological data (mostly from the Michigan Department of Environmental Quality, Geological Survey Division, MDEQ-GSD) including formation tops, wire-line logs, and driller's reports. Where appropriate we compiled these data into tabular spatial databases. These spatial databases were used to construct Geographic Information Systems files (both ArcGIS and Petra software),

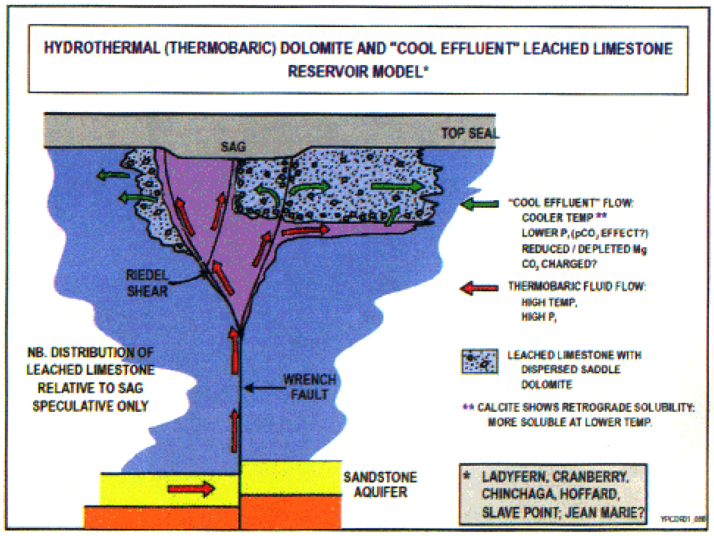


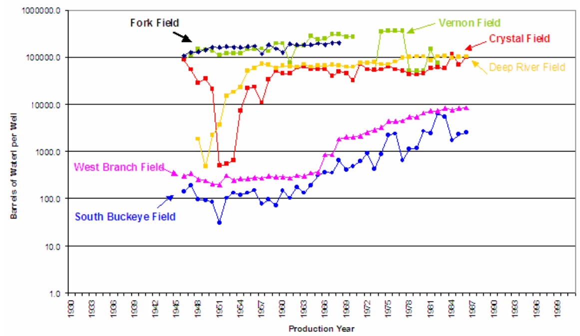
Figure 7. Generalized geometry and lithofacies model for fracture related hydrothermal dolomite reservoirs, from Strecker and others, 2005

as well as maps and cross sections of important geological properties in the Dundee - including the spatial distribution of dolomite versus limestone in the Dundee Formation relative to structural features and oil field occurrences in the Michigan Basin. Modern wireline logs in digital format were analyzed from over 400 wells. Quality controlled Dundee Formation tops from a data base with more than 25,000 wells (data base originated from J. R. Wood, MTU Subsurface Visualization Lab) were used in the structural mapping. The current availability of large institutional digital subsurface databases, modern digital well logs, readily accessible computational power, and appropriate software provides the opportunity to evaluate correlations amongst general structural and lithologic trends in the Dundee from a wide range of data sources. A limited number of modern litho-density well logs from across the basin provide an important source of information available for investigation of lithology in the Dundee Formation relative to spatial location and structural features in the Michigan Basin subsurface.

Dundee Field Water Production Characteristics

Field production characteristics in Dundee Formation fields (Figure 8a and b) define at least two distinct drive mechanisms basin-wide on the basis of water production and pressure decline: 1) bottom water and 2) gas expansion. Figure 8a shows per well water production from representative fields with two distinct trends of 1) relatively high water production per well from inferred bottom water drive dolomite fields (Fork, Vernon, Crystal; central basin dolomite fields, and Deep River; an eastern basin dolomite chimney field) versus 2) relatively low water production from probable gas expansion drive limestone fields (West Branch and South Buckeye; eastern basin limestone fields). Pressure decline is substantially greater in the gas expansion fields and initial bottom hole pressures are generally preserved in the inferred bottom water drive, dolomite fields. A similar breakout of field drive mechanisms is suggested by percent water cut plot (Figure 8b). The increase in water cut later in the production history of the eastern limestone fields is, in part, influenced by secondary recovery water flood projects. Facies related fields (both limestone and dolomite) in the Reed City member typically possess gas expansion type drive while upper Dundee/Rogers City dolomite fields possess bottom water

A.



B.

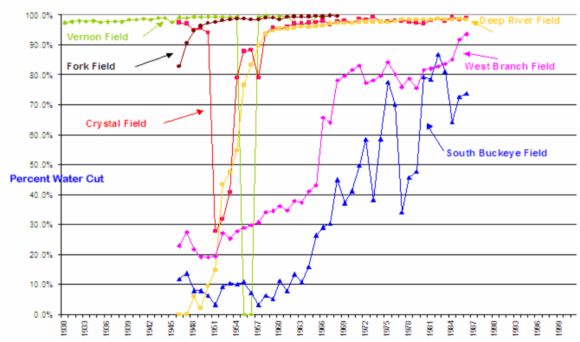


Figure 8a and b. Water production characteristics of Dundee field types.

drives that apparently tap a regional aquifer of substantially greater volume than any individual field.

Fracture Related Hydrothermal Reservoirs in Michigan

The significance of fracture-related mechanisms in the origin of important hydrocarbon reservoirs in Michigan is virtually undisputed. Fields in the Ordovician Trenton/Black River formation in Michigan, most notably the Albion-Scipio Field, are classic examples of geometrically complex dolomite reservoirs effectively modeled by the hydrothermal dolomite reservoir (HTDR) concept (Figure 9). Application of models for reservoirs of this generic type in other Michigan formations is controversial but of great current interest for both exploration and enhanced recovery in the petroleum industry.

Structural analysis of Michigan Trenton Black River (Hurley and Budros, 1990) and (more recently) Dundee Formation Fields (Prouty, 1988; Wood, 2003; and Budros, 2004; and others) suggests a relationship between probable reactivated basement wrench faults, anticlines with steep margins, and oil field occurrences. Riedel shear deformation mechanisms including complex flower structure fracture patterns are suggested as important components in the development of these dolomitized fields. The transport of dolomitizing hydrothermal fluids delivered to generally low permeability, primary limestone facies in the Rogers City Member in particular, is thought to result from flow through fractures associated with periodically reactivated wrench faults. Recent petrologic study of central basin, fractured upper Dundee/ Rogers City lithofacies (Luczaj, 2001), suggests temperatures of saddle dolomite formation in excess of 120^{o}C in several central basin wells, which is well above ambient burial temperatures.

Distribution of Wire-line Log Based Lithofacies in the Dundee Formation

Lithofacies in the Dundee Formation were investigated using an industry standard "quick-look" overlay methodology and digital litho-density wire-line logs. When Neutron porosity and Bulk Density logs are overlain on a common, limestone equivalent porosity scale, changes in lithology can be inferred with depth (Figure 10). Shale, tight and porous limestone, dolomite, and anhydrite are relatively confidently identified using this "quick look" overlay

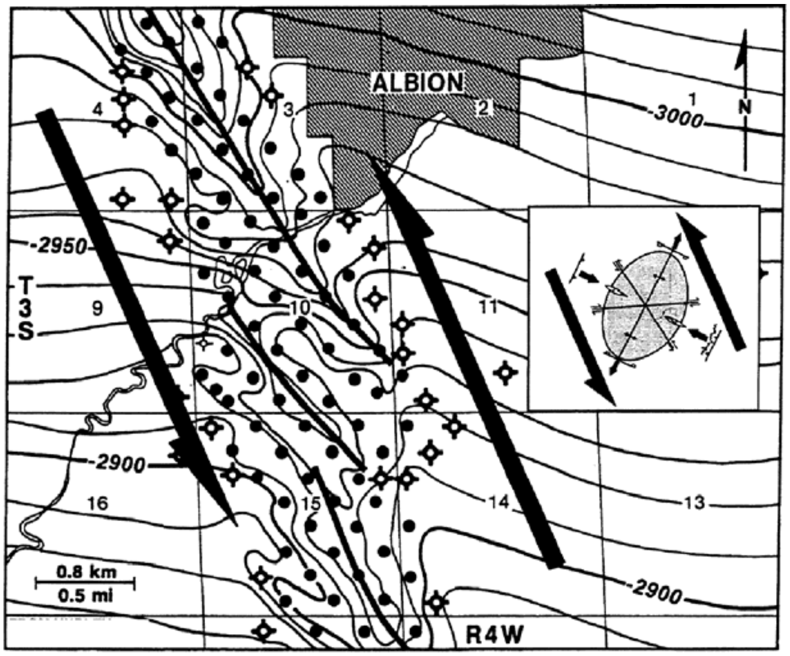


Figure 9 Model for Rieidel shear control on the Albion-Scipio fractured dolomite field, Michigan basin, from Hurley and Budros, 1990.

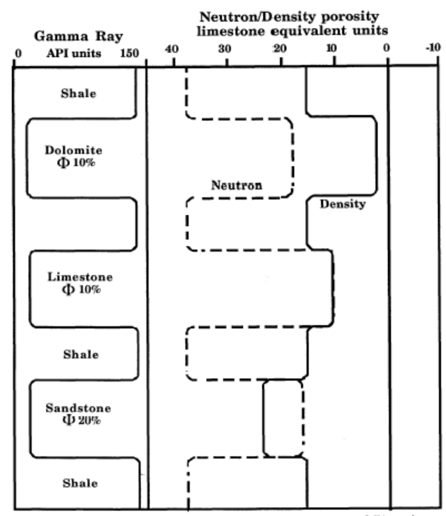


Figure 10. Hypothetical neutron-density overlay patterns for simple log-based lithofacies. The overlay uses a common calibration to an equivalent limestone porosity scale. (From Doveton, 1986).

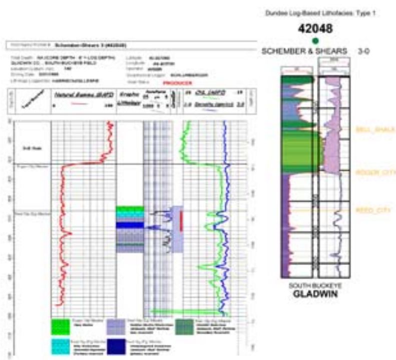
method and log-based lithofacies in the Dundee Formation can be interpreted. Since log-based lithofacies are dependant on bulk density properties it is not possible to distinguish dolomite facies with different textural properties or geological origins including overprinted dolomitization.

A wide range of dolomite versus limestone successions are observed throughout the basin (figures 11a-f; in both producing and dry holes) including six distinctive assemblages:

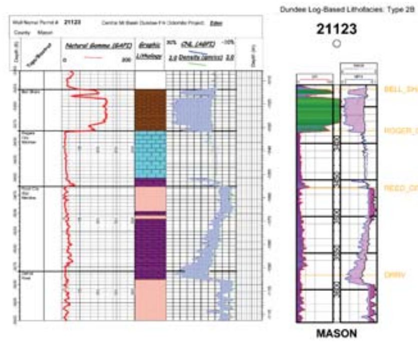
1. No dolomite in the Dundee in the eastern basin (Gladwin Co., Figure 11a; lithofacies assemblage 1)
2. Complete dolomitization of Reed City Member (and associated Reed City "Anhydrite") with no dolomite in the Rogers City member; western-most central basin, (Mason Co., Figure 11b; lithofacies assemblage 2)
3. Complete dolomitization of both Dundee members in the central basin (Isabella Co., Figure 11c; lithofacies assemblage 3)
4. Partial/minor dolomitization of the Reed City (and associated Reed City Anhydrite) and no dolomite in the Rogers City west-central basin (Mecosta Co. Figure 11d; lithofacies assemblage 4)
5. Partial dolomitization (bottom up) of the Reed City and no dolomite in the Rogers City in the central basin (Isabella Co., Figure 11e; lithofacies assemblage 5)
6. Partial dolomitization in the Reed City/Rogers City undivided (top down) and minor associated Reed City Anhydrite in the northwestern central basin (Missaukee Co., Figure 11f; lithofacies assemblage 6).

Regional Dundee Structure Mapping and Log-based Lithofacies Distribution

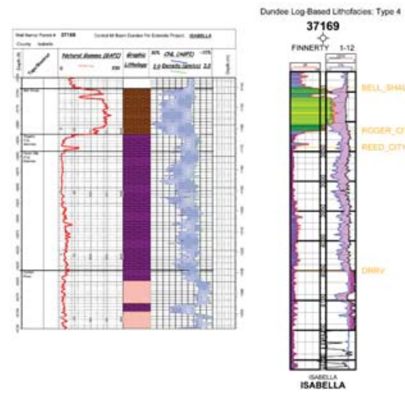
Top Dundee structure was mapped using an extensive tops data base compiled from data made available by James Wood, Michigan Tech, Subsurface Visualization Lab. Ten central Michigan Basin counties were each individually analyzed using geostatistical methodology and industry standard ArcGIS software. Structure contour and grid maps were created for each



11a

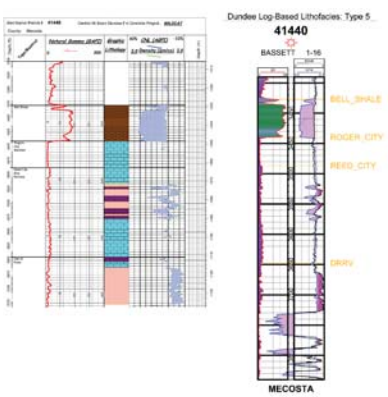


11b

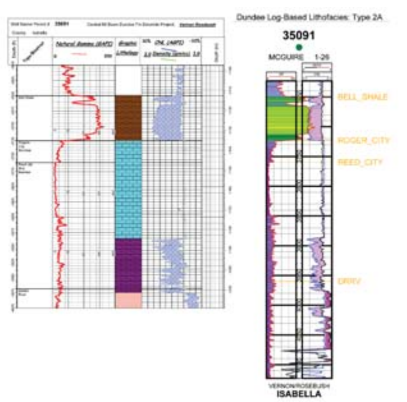


11c

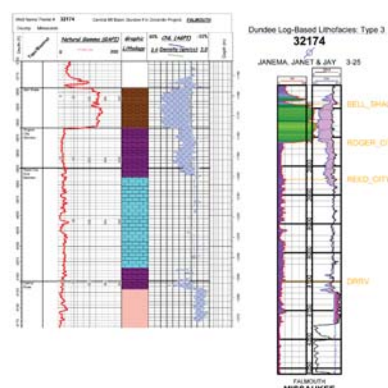
Figure 11a,b, and c. Litho/density log-based Dundee Formation lithofacies assemblages 1, 2, and 3 respectively. See text for discussion.



11d



11e



11f

Figure 11d,e, and f. Litho/density log-based Dundee Formation lithofacies assemblages 4, 5, and 6 respectively. See text for discussion.

county through a quality control procedure involving iterative error analysis. Apparently spurious data points were eliminated from the tops data set by county until root mean square error (RMSE) of measured versus predicted tops in that county was less than 20 ft (the displayed contour interval). Some analyses produced RMSE well below 20' (Figure 12). A ten county composite Dundee top structure prediction map was then produced (Figure 13) that shows a strong preferred northwest-southeast grain and a less pronounced, essentially conjugate, northeast-southwest grain.

The distribution of productive, Dundee dolomite fields in the central basin is typically associated with structural trends with a predominant 310^{o} - 130^{o} and a conjugate 40^{o} - 220^{o} orientation. Areas marked by a convergence of these structural grains typically coincide with dolomitized Dundee fields. Small-scale spatial variation and complex geometric patterns of dolomitization in several counties supports local rather than regional dolomitization in the upper Dundee due to fracture-related fluid migration pathways (e.g. Figure 14). Dolomitization patterns in the lower Dundee, Reed City Member have wider spatial distribution but may represent a complex interplay between primary facies controlled dolomitizing fluid conduits and fracture related conduits. If the geometrically complex dolomitization in the upper parts of the Dundee occurs in what was regional tight primary limestone of the Rogers City, this relationship is almost certainly the result of fracture related hydrothermal dolomitization associated with geometrically complex matrix fracturing.

Field Scale Structure Mapping and Log-based Lithofacies

Field scale structural mapping of top Dundee with high quality, wire-line log controlled well data indicates a geometrically complex spatial correlation between subtle structure and reservoir facies variations in the Upper Dundee/Rogers City Member. High resolution structure contour mapping (5'-10' contour interval) based on high quality top and lithofacies picks, suggests top Dundee surface irregularities that are best interpreted as faults with small throw of generally less than tens of feet in two Dundee fields, Winterfield (Clare Co., Figure 15a) and Vernon-Rosebush (Isabella Co, Figure 15a). In the Winterfield field a transition from dolomitized upper Dundee/Rogers City to undolomitized upper Dundee occurs within less than

0.3 mi. The alignment of wells with dolomitized upper Dundee/Rogers City is in accordance with a 40^{o}- 220^{o} orientation superimposed on an overall 310^{o} - 130^{o} trend for the field. A nearby extension of the Winterfield field (not shown) with a linear, 310^{o} - 130^{o} field orientation and probable fracture-related Dundee production (Chittick, 1996).

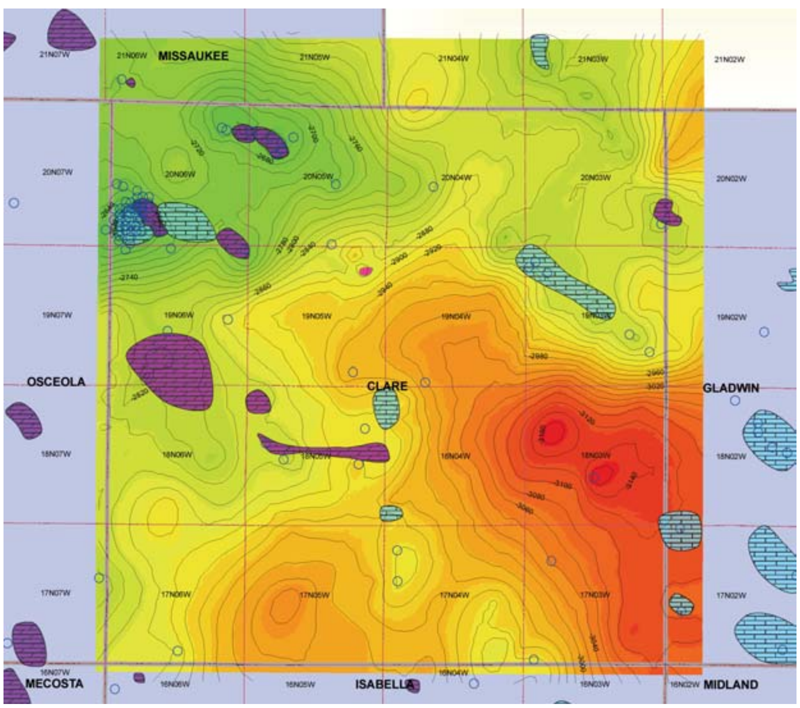


Figure 12. Example of central Michigan basin county structure map on top Dundee Formation with superimposed Dundee fields and inferred reservoir lithofacies.

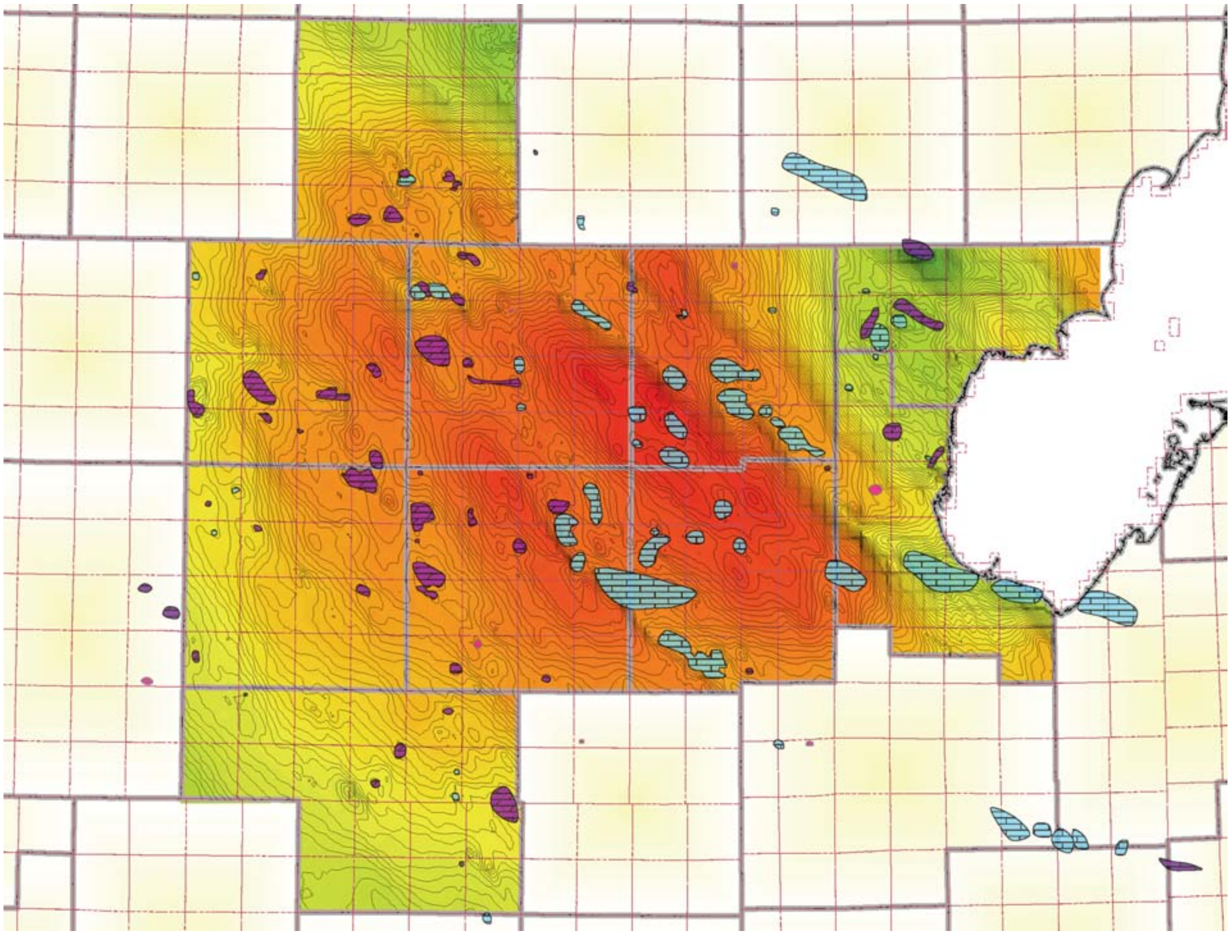


Figure 13. Michigan central basin 10 counties structure map on top Dundee Formation with superimposed Dundee fields.

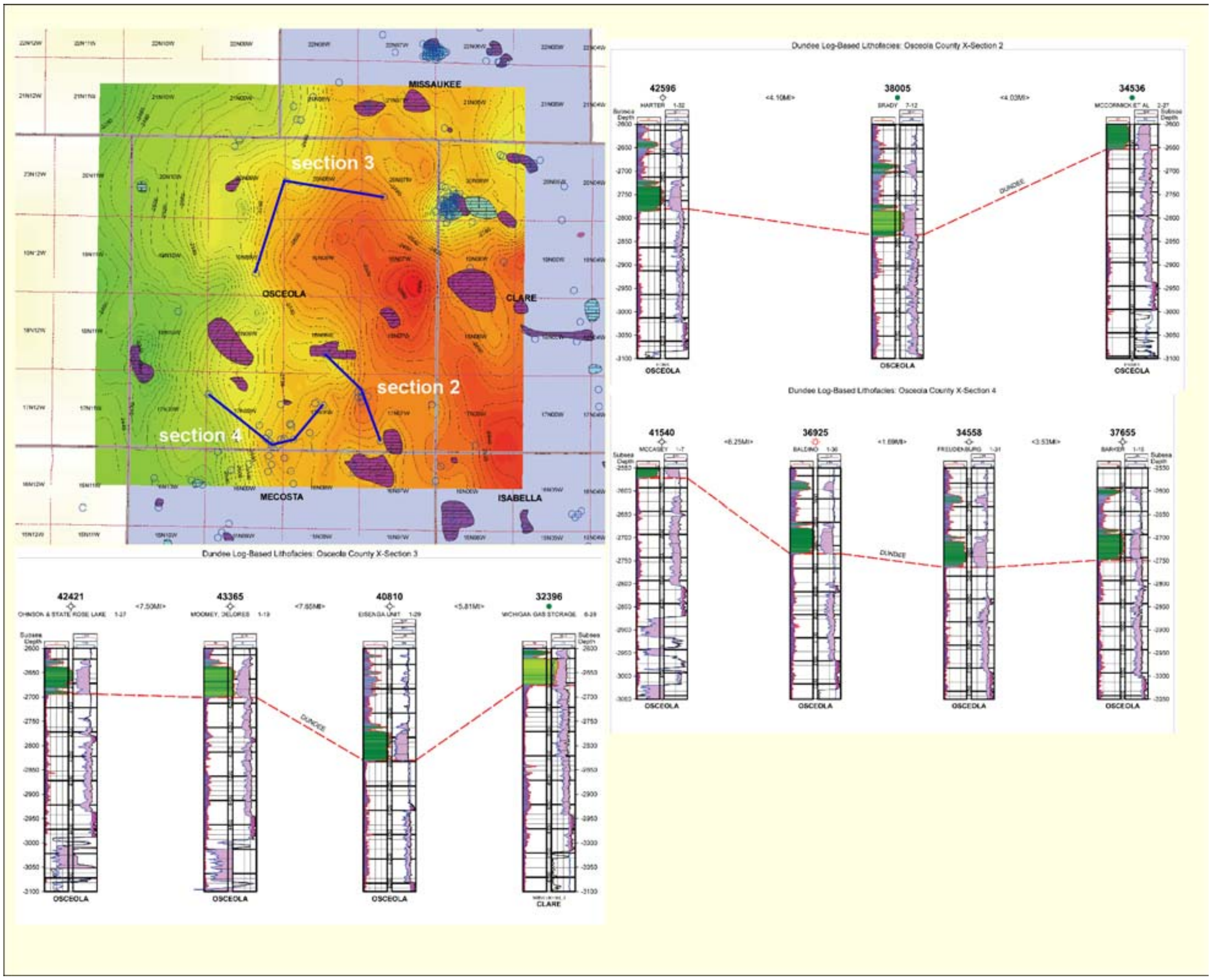


Figure 14. Osceola County structure map on top Dundee and litho-density "quick look" lithofacies assemblage cross-section. Small-scale spatial variation and complex geometric patterns of dolomitization supports local rather than regional dolomitization in the upper Dundee/Rogers City due to fracture related fluid migration pathways.

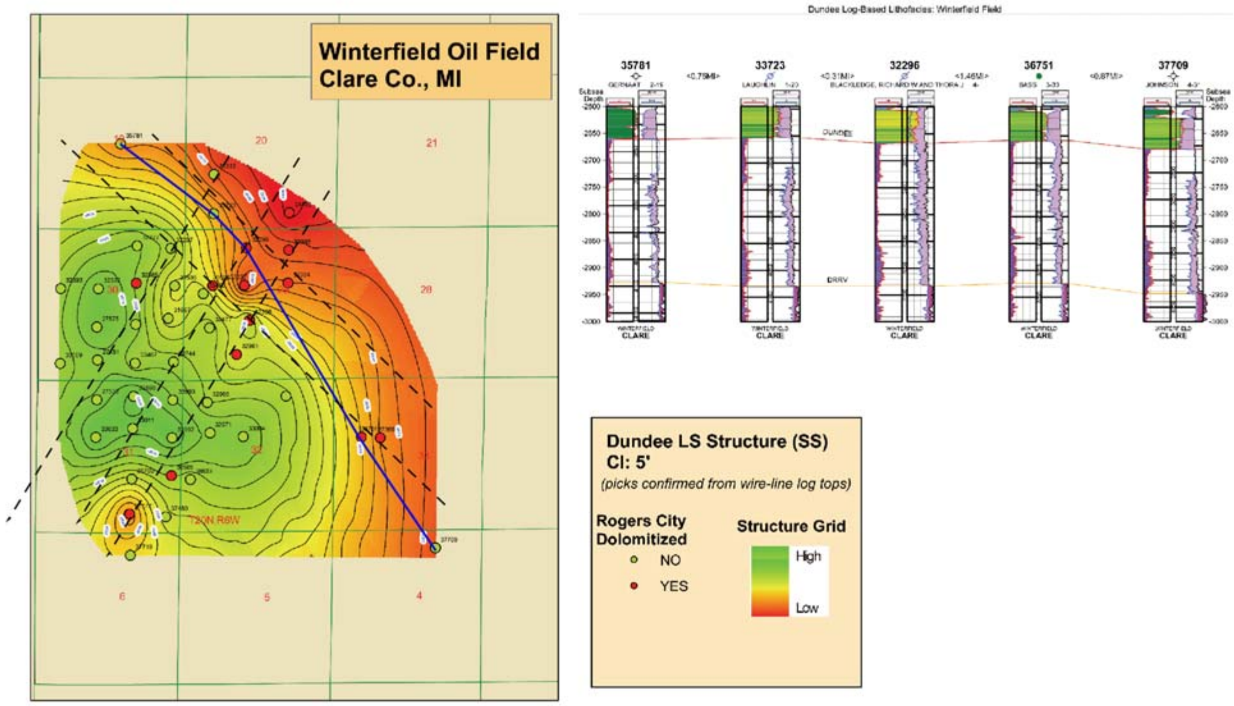


Figure 15a. High resolution (5' contour interval) structure contour map of the Winterfield field, Clare Co. Note small spatial scale variation in upper Dundee dolomite distribution associated with interpreted small throw displacement faults (dashed lines) with ~310^{o}-130^{o} and 40^{o}-220^{o} orientation.

A similar, relationship between small scale structure and the inferred distribution of Dundee dolomite reservoirs is interpreted in the Vernon-Rosebush field of Isabella Co. Small scale structural deformation of the top Dundee surface is mapped in the north-northwest extension of the Vernon-Rosebush structure (Figure 15b). In the down dip north and west portion of the Vernon-Rosebush field, sparse log control can be interpreted to indicate complete dolomitization of the Dundee associated with high initial oil production rates. The IP's (to several thousand BOPD) are comparable to many central basin Dundee fields that are probably fracture-related. Less than 2 miles to the south and east, which is up structure, the Dundee contains limestone from bottom to top.

Interpreted faults and related fractures apparently propagated to the Dundee-Bell Shale contact in places throughout the central basin (and apparently elsewhere n the basin) and may have provided geometrically complex secondary conduits locally for dolomitizing fluids that permeated upwards through the otherwise regional tight limestone of the upper Dundee/Rogers City.

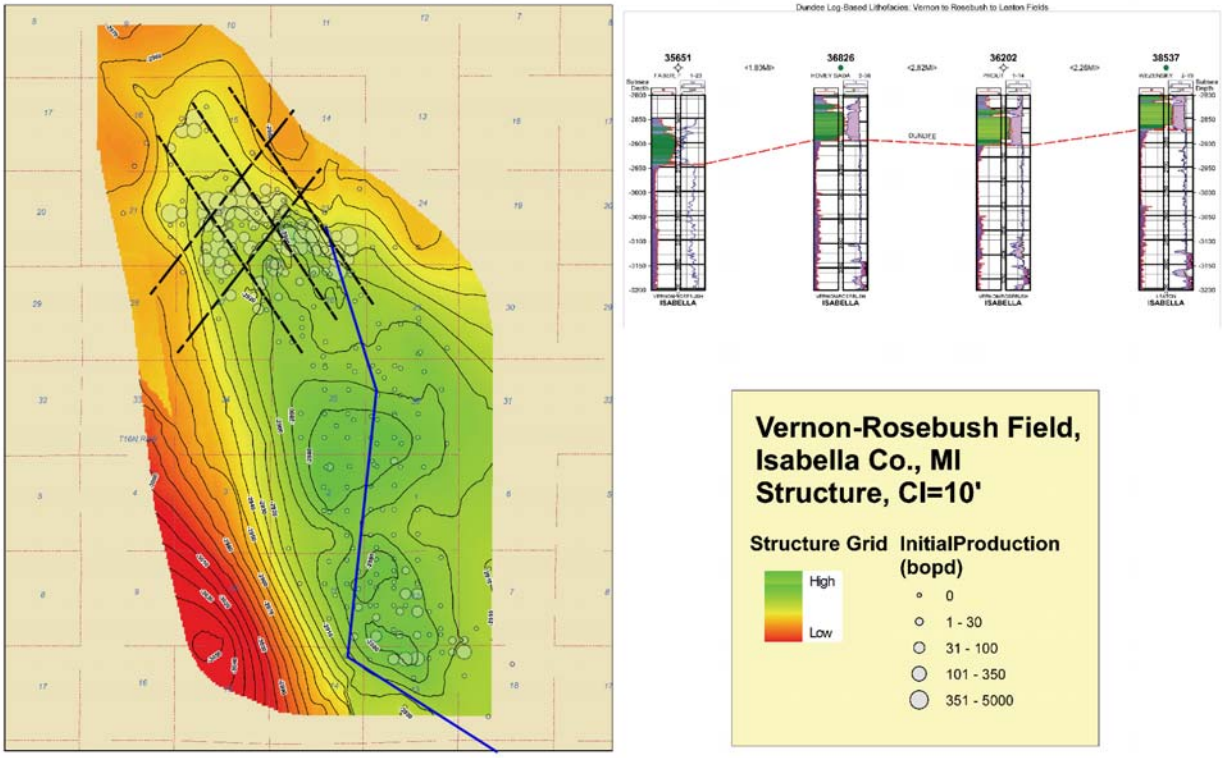


Figure 15b. High resolution (10’ contour interval) structure contour map of the Vernon-Rosebush field, Isabella Co. High initial production in wells in the Vernon (northwest, down structure) portion of the field coincide with interpreted small throw displacement faults (dashed lines) with ~310 °-130° and 40 ° -220° orientation. One litho/density well log in the Vernon area (Faber well) suggests complete dolomitization of the entire Dundee section while wells to the southeast (Rosebush area) are mostly limestone coincident with relatively simple, open structural style.

Implications for Petroleum Geology in Michigan and other U.S. Hydrocarbon Basins

Our mapping efforts to date, which have focused in large part on the Devonian Dundee Formation, have important implications for both new exploration plays and improved enhanced recovery methods in the Dundee "play" in Michigan – i.e. the interpreted fracture-related dolomitization control on the distribution of hydrocarbon reservoirs. In an exploration context, high-resolution structure mapping using quality-controlled well data should provide leads to convergence zones of fault/fracture trends that are not necessarily related to structural elevation. Acquisition of high-resolution seismic data in areas with prospective structural grain may provide decreased risk for fractured Dundee exploration drilling.

Application of fracture models to reservoir characterization in secondary and tertiary recovery projects in existing fractured Dundee fields, may result in substantial additional recovery from fields that typically had low (<30%) primary recovery factors. Careful consideration of fracture orientations and water coning problems should decrease risk in enhanced recovery activities.

Undoubtedly more complex, hybrid reservoir types exist in dolomitized lower Dundee/Reed City Member lithofacies in the central basin. This is anticipated as a result of complex, early fluid flow through primary limestone pore conduits within a reflux system, in addition to fracture generated pathways in fault/fracture convergence zones. Much additional work is necessary to understand Reed City Member dolomitization processes in Michigan and implications for petroleum geology and is a primary goal of Phase II efforts.

INITIAL SUMMARY OF CURRENTLY AVAILABLE GEOLOGIC DATA (TASK 2)

Ordovician Trenton/Black River Production

The Ordovician Trenton-Black River Formation is a fractured, dolomitized reservoir that has produced 140 MMBO and 260 BCFG in the State of Michigan. However, theories concerning the nature of fracturing, the controls exerted by the original depositional rock type and pattern, the extent of dolomitization, the types of fluids involved, and the various stages of diagenesis are still evolving. All previous studies deal only with data from specific field areas. There has never been a basin-wide synthesis and analysis of these data despite the fact that the Trenton-Black River Formation is one of the largest hydrocarbon producing reservoirs in the state. It is doubtful that the current Trenton-Black River exploration model, developed from independent field studies, adequately encompasses all the exploration and exploitation opportunities that exist for this reservoir in the Michigan Basin. Increasing the current total recovery for this unit by only 1% would add 1,380,000 BO and 2.6 BCF to the already recovered reserves. It is reasonable to expect that a comprehensive, basin-wide examination of the Trenton-Black River Formation, resulting in the development of additional exploration models and methods could ultimately produce a 5% increase in recoverable reserves (6.90 MMBO and 13 BCF).

Trenton-Black River Discovery and Development

Drilling began in 1884 along the Findlay-Kankakee Arch in Indiana and Ohio (Fig 58, Davies, 1996, 2000) resulting in the first Trenton-Black River discoveries. This led to the drilling of over 100,000 wells and the production of 500 MBO along the Bowling Green Fault Zone.

The first commercial Trenton-Black River discovery in the State of Michigan occurred in 1936 in Monroe County. This resulted in the Deerfield Field located along the Lucas-Monroe monocline, an extension of Bowling Green Fault zone in Ohio. Reservoir quality dolomite lenses in the upper 125’ of the Trenton Group produced more than 608 MBO by 1959 from 40 wells drilled on 360 acres.

The Albion-Scipio Field, a giant (>120 MMBO) Trenton-Black River field located in Calhoun & Hillsdale Counties, Michigan was discovered in 1955 – 1958 (Davies, 1996, 2000).

The Scipio Field discovery well was the Houseknecht No. 1 (Sec 10, T5S-R3W – Hillsdale Co.) which was originally drilled for Devonian gas but proved dry. It was then deepened based upon the advice of a psychic family friend, encountered oil at 3900', and was completed at 140 BOPD with "considerable" gas. The Albion Field was discovered by the Rosenau No. 1 (Sec 23, T3S-R4W, Calhoun Co.) and completed for 200 BOPD. Subsequent drilling discovered the Pulaski, Barry, Sponseller, Van Wert, and Cal-Lee Fields; all to become part of the Albion-Scipio Trend. Over 961 wells were drilled by 1986, of which 573 are still producing.

Stoney Point Field (5 miles east and sub-parallel to Albion-Scipio) was not discovered until 27 years later in 1982 when the JEM Casler No. 1-30 (Sec 30, T4S-R2W, Jackson Co.) encountered dolomite reservoir 115' into the Trenton at 3910'. This well hit lost circulation at 4248'. Casing was set and the well was tested at 2000 BOPD from perforations at 4161' - 4179'. The bottom hole pressure drop never exceeded 3 psi and the well was put on production at 220 BOPD. Two hundred and ten wells were drilled around the Stoney Point Trend between 1983 and 1987. Seventy five wells were oil and gas producers.

Estimated oil-in-place figures are difficult to accurately calculate due to difficulties in establishing a reliable porosity number; however, Scipio Field is estimated to have 170 MMB OOIP, Albion Field is estimated to have 120 MMB OOIP. No figures are available for Stoney Point Field. There are 18 Trenton-Black River fields that have produced in Michigan.

Stratigraphy and Structure

The Trenton-Black River Formation was originally deposited during the Ordovician in open marine conditions. Wackestone - mudstones were deposited on a basin-wide scale. Trenton-Black River carbonates in the Stoney Point Field area (south-central Michigan) are open marine, subtidal carbonates, typically crinoidal packstones/wackestones and mudstones with pervasive burrowing. Trenton rocks in the Deerfield Field area (SE Michigan) prograde from open marine to intertidal carbonates while Black River rocks remain subtidal (Davies, 1996, 2000). The Trenton is overlain by the Utica Shale that forms a regional seal. This is in turn overlain by reef and inter-reef carbonates of the Niagara Formation and Salina Formation evaporates.

Repeated reactivation of a Precambrian left-lateral wrench fault system (en echelon faults with a total of 2.5 miles of offset) occurred throughout the early to mid Paleozoic. These faults (dominant set oriented N30W, conjugate set oriented east-west) are thought to have provided conduits through which dense Salina residual evaporite brines were able to flow downward into the Trenton-Black River formation. Dissolution and dolomitization of the Trenton-Black River occurred immediately adjacent to faults resulting in long, linear, porous dolomite reservoirs associated with downward collapse of overlying units. The collapsed interval extends into the Devonian section where it dies out. Fractures in the Utica Shale must have healed at the cessation of faulting to provide a seal for the Trenton-Black River reservoir. Tight un-dolomitized limestones act as lateral stratigraphic seals (Allen and Wiggens, 1993). DeHaas and Jones (1984, 1989) proposed cave development related to karsting responsible for lost-circulation zones; however, this theory has been largely discounted by recent workers.

Budros (APPG Annual Meeting, 2004) proposes that "sags" or "grabens" overlying dolomitized reservoirs (thereby defining Trenton-Black River fields) are in fact negative flower structures due to Reidel shear faulting with trans-tension and are not the result of previously considered collapse due to dissolution. He also proposes that some fields are characterized by positive flower structures produced by Reidel shear faulting with compression.

Faulting has compartmentalized the Albion-Scipio Trend. These compartments are probably due to a combination of Reidel shear negative and positive flower structures along the same fault trend; however, this hypothesis demands further investigation. These discontinuities do account for dry holes drilled apparently "directly on trend" (Figure 62 – Davies, 1996, 2000).

Fields such as Deerfield Field exhibit a more circular pattern rather than a long, linear NW - SE pattern typically considered indicative in the current Trenton-Black River exploration model. It is thought that secondary east-west oriented faults may have played a more significant role in the development of dolomitized reservoir facies in the Deerfield Field. Fractures and faults with minor displacement play an important roll controlling dolomitization and porosity development (Davies, 1996, 2000).

Trenton-Black River Reservoir Characteristics

Reservoir dolomites are composed of coarse crystalline dolomitzed limestone host rocks that are vuggy and cavernous. Fractures and vugs are often solution enlarged and contain white saddle dolomite with minor anhydrite. Porosity normally ranges from 2-5%, but 8-12% porosity is present, though uncommon. Permeability is extremely variable (0.01 – 800 md) but is generally low (85% of samples < 10 md). Porosity and permeability plots do not show any uniform relationships. Isotopic, fluid inclusion and water chemistry analyses all indicate a hydrothermal genesis for reservoir dolomites with a dual source of fluids from the Salina and Trenton - Precambrian Formations (Allen and Wiggens, 1993).

Origin of Dolomite

Shortly after discovery of the Albion-Scipio Trend, Burgess (1960) determined that reservoir dolomite was a secondary mineral formed as Cambrian and Lower Ordovician waters moved up along fracture zones (analogs - Dover and Colchester Fields in Ontario).

Ells (1962) observed that Albion-Scipio Field dolomites were similar to Mississippi Valley-Type (MVT) lead-zinc mineral deposits. He proposed that magnesium-bearing waters ascending through fractures were responsible for dolomitization.

Beghini and Conroy (1966) stated that Trenton-Black River reservoirs were formed by pre-Black-River Group waters that moved through faults and fractures to produce secondary dolomite.

Buehner and Davis (1968) concluded that the Trenton-Black River reservoir facies was epigenetic dolomite related to a fault system.

Shaw (1975) described a mineral assemblage (including sphalerite) in Albion-Scipio cores similar to MVT mineral deposits. He noted 2-phase fluid inclusions in Albion-Scipio dolomites and pore filling saddle dolomites that he believed were precipitated from fluids at a minimum of 80 degree C. He also identified a liquid-hydrocarbon phase in some fluid inclusions indicating hydrocarbons were present at time of cementation. These observations allowed him to propose a model of replacement dolomitization and development of intercrystalline porosity during the Middle to Late Silurian by waters percolating through fractures. Magnesium was sourced from underlying Prairie du Chien dolomite or Trempealeau Formations. Then, a second phase of dolomitization occurred during Lower to Middle Devonian as hot fluids from the basin center created cavernous porosity, subsequent collapse, and precipitation of a MVT assemblage.

Ardrey (1978), DeHaas and Jones (1984, 1989) proposed that diagenesis of the Trenton-Black River in Albion-Scipio area was due to exposure as indicated by the top-of-Trenton unconformity. They also stated that dolomitization must have resulted from a mixing model based on the observation that Trenton Formation water is less saline than water in shallower horizons; therefore, it could not be of hydrothermal origin.

Taylor and Sibley (1986) identified 3 major types of dolomite (1) regional dolomite not associated with the field area, (2) cap dolomite that occurs in the top 40 feet (related to interaction of the Trenton with Fe-rich fluids formed during the de-watering of the overlying Utica Shale) (3) fracture-related dolomite (formed during deeper burial at approximately 80 degrees C based on geochemical results).

Budai and Wilson (1986) identified various MVT accessory minerals, including pyrite, calcite, anhydrite, barite, celestite, sphalerite, and fluorite in association with saddle dolomite cements. They proposed a hydrothermal model with Paleozoic and Precambrian basement rock as sources of iron, sulfur, and other trace metals.

Hurley and Cumella (1987) proposed a model based on (1) carbon, oxygen, and strontium isotopes, (2) fluid-inclusion geothermometry, (3) brine geochemistry, and (4) regional hydrologic constraints. Dolomitizing fluids were thought to be Silurian-Devonian hypersaline sea-waters that moved down fracture zones to meet with hot limestone-dissolving fluids moving up from the basement. These fluids mixed in a pattern consistent with the known distribution of dolomite reservoirs and lost-circulation zones. This model is supported by Coniglio et al (1994) for Ordovician rocks in Ontario (Figure 67 - Davies, 1996, 2000).

<u>Exploration</u>

Originally, the Albion-Scipio Field was discovered by the advice of a psychic. “Trendology” quickly become the exploration method of choice as the linear field pattern began to emerge. Indications of a northwest-southeast linear fracture zone associated with a top-of-Trenton synclinal sag (up to 60’ recognized in early producing wells) has been the long held exploration model for the Trenton-Black River Formation.

Gravity was used through the 1960's and early 70's to define basement faults along the Albion-Scipio Trend. This met with limited drilling success because dolomite porosity mutes the density contrast between the regional limestones and dolomite reservoir rocks.

Magnetics was used in the 1970's to detect basement discontinuities and faults; however, this also proved to have limited use. The giant Albion-Scipio does not appear as an individual feature on magnetic maps. Recently, micromagnetic surveys and resistivity profiles have been employed, but their significance is not yet proven.

Reflection-seismic is currently the primary exploration method; however, there are problems associated with this technique: (1) variable till overburden thicknesses produce noise and statics problems, (2) secondary porosity, the dominant reservoir characteristic, is not detected by P-waves, (3) reservoir dolomites (2-5% porosity) have an acoustic impedance similar to the regional limestones, and (4) reservoir geometries are difficult to image. To date, reflection-seismic Trenton-Black River discoveries have been based on: (1) disruptions (sags) at the Trenton event, (2) internal waveform changes, (3) disruption of lower events, and (4) recognition of faults from offsetting events and/or diffractions.

Soil gas geochemistry studies above Scipio field showed no correlation between soil gas and producing parts of the field; however, soil gas geochemistry reportedly played an important role in the Stoney Point Field discovery.

Exploitation

Secondary Recovery has been minimal. Results were discouraging from a pilot waterflood of the Haskell Unit (near south end Scipio Field). Marathon Oil has drilled a number of Trenton-Black River horizontal wells that show considerable promise for future exploitation.

Summary

This is the first comprehensive, systematic study to determine the basin-wide relationships of: (1) original carbonate depositional patterns, (2) formation of early stage diagenetic dolomites vs. later stage burial and hydrothermal dolomites, (3) types and patterns of faulting, (4) types and patterns of dolomitization resulting from this faulting, (5) resulting reservoir rock quality,(6) oil accumulations (field delineation and orientation), and (7) hydrocarbon production. The current Trenton-Black River exploration model of looking for a seismic sag associated with basement faults in long linear patterns appears to be only partially correct. It is possible, in light of evolving geological concepts concerning the Michigan Basin, that other styles of Trenton-Black River fields exist. However, no exploration models covering these variations have yet been developed. This work will provide numerous opportunities to expand our understanding of Trenton-Black River hydrocarbon accumulations and significantly add to known reserves.

Silurian Niagaran Production

General Observations

1. Production data for the Niagaran Trend is generally good. The play began in the early 1950's and hit it's peak during the 1970's-1980's. Digital data bases developed by the state beginning in 1981 include a large portion of the data for this play.

2. The log plot of the data displays a curve typical of that for a mature play. Nearly all field sizes are represented and no "gaps" in field size occur. The slope of the curve is shallow indicating full representation of each field size. Future potential is probably resource limited for this particular exploration model; however, new technology, combined with a new/expanded exploration model could potentially re-set the curve to a higher level.

3. There are 1,162 fields in this play. There are 1,063 fields producing oil. This volume of data makes it difficult to plot trends including individual field names. Rather, data can best be examined as categories based upon field size. "Cumulative Oil Production" can be broken down into 5 basic categories: 1.) Fields 1-10 million barrels cumulative oil production, 2.) Fields 100,000 – 1 million barrels cumulative oil production, 3.) fields 10,000 – 100,000 barrels cumulative oil production, 4.) fields 1,000 – 10,000 barrels oil cumulative production and 5.) fields less than 1,000 barrels cumulative oil production.

4. Fields making less than 1,000 barrels oil cumulative production are probably not economic based upon oil production alone. The sharp drop-off in fields of this size is probably due to the fact that no one purposely looks for this sized field. However, a few disappointing fields of this size do occur and are produced to recover at least some of the cost of exploration and development. These fields, in most cases, are associated with gas production that makes the venture economic.

5. Gas is produced in 991 fields compared to oil being produced in 1,063 fields. Gas production volumes remain somewhat level in relationship to oil production volume (1 million BOE).

6. Brine is produced in 664 fields. Production of brine is roughly related to oil production. The larger oil fields all produce brine whereas the smaller the oil field, the less likely it is to produce brine. Only 8 fields produce only gas and brine. Brine volumes are roughly related to oil volumes. Only 28 fields produce more brine than oil. (refer to Cumulative Oil-Gas-Brine Production by field Graph)

7. The State of Michigan imposes a 200 barrel-per-day maximum allowable on production which often distorts the true capabilities/performance of the affected wells.

8. The graph of "Discovery Size (Cumulative Oil) by Year of Discovery" displays a wide variety of field performance for each year. Although originally kicked-off in 1950, Niagaran fields did not hit peak oil productivity until 1971 when drilling boomed with the discovery of 32 new fields that year. The 1970's represent the "best times" for Niagaran discoveries, with a sharp decline after 1981. This data set does not include the onset of horizontal drilling during the 1990's.

9. There are 1,162 fields in the Niagaran Trend. The oldest field in the trend was discovered in 1950. Only 9 fields in the Niagaran Trend have produced more than 35 years. Nearly one half of the fields have produced for 15 – 30 years (531 fields). Only 181 fields have

produced for 5 years or less. Seventy-three fields were either produced for less than one year or not produced at all.

10. "Cumulative Oil Production" varies substantially when plotted against "Years of Production." However, the best producers in each age bracket show impressive results. Nearly 10,000,000 barrels of cumulative oil have been produced by fields in the 30 to 50 year age bracket. Fields in production from 22 years to 30 years have top producers in the 1-5 million barrel range. Top producing fields in the 5 – 22 year bracket still hit the 1 million barrel mark other than for year 9. Even fields in production for only 1 year have obtained the 100,000 barrel mark.

Current Activity

1. Fields from each of the 5 basic categories defined above will be correlated to the newly developed index covering data quantity, quality and availability for each field. Fields in each category ranking high in data coverage will be selected for detailed study.

Devonian Dundee Trend Production

General Observations

1. Production data for the Dundee Trend is generally good. Dundee production statistics go back to 1934 although commercial Dundee production began in 1928 and has remained a stalwart of the Michigan Basin ever since. Its production ranks second only to that of the Niagaran Trend; however, the Niagaran Trend contains 1,162 fields vs. only 178 fields in the Dundee Trend.

2. The log plot of the data displays a curve typical of that for a mature play. Nearly all fields sizes are represented and no "gaps" in field size occur. The slope of the curve is shallow indicating full representation of each field size. Future potential is probably resource limited for this particular exploration model; however, new technology, combined with a new/expanded exploration model could potentially re-set the curve to a higher level.

3. There are 178 fields in this play. There are 155 fields producing oil. This volume of data makes it difficult to plot trends including individual field names; therefore, data has been examined as categories based upon field size. "Cumulative Oil Production" can be broken down into 7 basic categories: 1.) 8 Fields making 10-50 million barrels cumulative oil production, 2.) 30 fields 1 – 10 million barrels cumulative oil production, 3.) 50 fields making 100,000 – 1 million barrels cumulative oil production, 4.) 39 fields making 10,000 – 100,000 barrels oil cumulative production and 5.) 20 fields making 1,000 – 10,000 barrels cumulative oil production, 6.) 8 fields making 0 – 1,000 barrels cumulative oil production, and 7.) 14 fields making 0 oil production.

4. Fields making less than 1,000 barrels oil cumulative production (9 fields) are probably not economic based upon oil production alone. The sharp drop-off in fields of this size is probably due to the fact that no one purposely looks for this sized field. However, a few disappointing fields of this size do occur and are produced to recover at least some of the cost of exploration and development.

5. Gas is produced in 41 fields compared to oil being produced in 155 fields (although many fields may have initially had gas, production was limited due to infrastructure and much of the gas production was flared).

6. Brine is produced in 141 fields. Only 13 oil fields do not produce brine. Only 4 gas fields do not produce brine.

7. The State of Michigan imposes a 200 barrel-per-day maximum allowable on production which often distorts the true capabilities/performance of the affected wells.

<u>Current Activity</u>

1. Work is currently underway to further develop data covering Reed City vs. overall Dundee Formations.

2. Dundee Cumulative production vs. Year Discovered data is currently being edited for analysis.

3. Fields from each of the 7 basic categories defined above will be correlated to the newly developed index covering data quantity, quality and availability for each field. Fields in each category ranking high in data coverage will be selected for detailed study.

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APPENDIX I
INITIAL SUMMARY OF CURRENTLY AVAILABLE GEOLOGIC DATA (TASK 2)

Ordovician - Trenton-Black River Production Analysis Data and Graphs
(Prairie du Chien, Trempealeau generally not productive)

DISCOVERY

- 1884 – Drilling begins on Findlay-Kankakee Arch in Indiana and Ohio
  - Indiana-Lima trend
    - 100,000 wells
    - 500 MBO Bowling Green Fault Zone (Albion-Scipio analog)
- 1917 – SW Ontario – Dover Field
  - narrow, elongate, east-west trending dolomitized reservoir with synclinal expression
  - highly variable dolomitization
  - 4 separate pools
  - production from 2800-3200’
  - 249 KBO and 12.8 BCF CUM
- 1920 – Dundee Township, Monroe County, Michigan
  - First Trenton oil in Michigan
  - Noncommercial
- 1936 – Deerfield Field, Monroe County Michigan
  - First Commercial Trenton oil in Michigan
  - Along the Lucas-Monroe monocline
    - Extension of Bowling Green Fault zone in Ohio
  - Dolomite lenses in upper 125’ of Trenton Group
  - 1959 – 40 wells drilled on 360 acre field
  - 1959 – 608 KBO CUM
- 1954 – Northville Field, Washtenaw, Oakland and Wayne Counties, Michigan
  - drilled as gravity prospect
  - faulted anticline
  - production from
    - Dundee (Devonian)
    - Salina-Niagaran (Silurian)
    - Trenton-Black River (Ordivican)
      - Fractured and dolomitized limestones
      - East flank of structure
      - Production is fault associated
- 1955-58 – Albion-Scipio, Calhoun & Hillsdale Counties Michigan
  - 1955 - Scipio Discovery Well – Houseknecht No. 1 (Sec 10, T5S-R3W – Hillsdale Co.)
    - Originally drilled for Devonian gas - Dry

Deepened on advice of family psychic friend
1/57 - Encountered oil @ 3900'
Comp @ 140 BOPD and "considerable" gas
9/57 – Confirmation well – Stephens No. 1 (Sec 10, T5S-R3W – Hillsdale Co.)
Spetacular blowout – hit lost circulation @ 3769' (235' into Trenton)
Shut-in – craters began to form around location
Flowed for 25 houras @ 15 MMCFGPD
11/58 – Albion Discovery well Rosenau No. 1 (Sec 23, T3S-R4W, Calhoun Co.)
Comp @ 200 BOPD
Subsequent drilling discovered Pulaski (1959), Barry, Sponseller, Van Wert, Cal-Lee Fields – All part of the Albion-Scipio Trend
1986 - 961 wells drilled, 573 still producing
1989 – 330 Trenton penetrations in Albion Field
631 Trenton penetrations in Scipio Field

12/82 – Stoney Point Field Discovery (sub-parallel to Albion-Scipio 5 miles east)
JEM Casler No. 1-30 (Sec 30, T4S-R2W, Jackson Co.)
Encountered dolomite reservoir 115' into Trenton @ 3910'
Hit lost circulation @ 4248', casing set
Tested @ 2000 BOPD from perfs 4161'-4179'
BHP drop never exceeded 3 psi
Put on production @ 220 BOPD (1/83)
1983 –1987 – 210 wells drilled around Stoney Point Trend
1987 – 75 wells oil and gas producers in Stoney Point Trend

STRATIGRAPHY

Trenton – Limestone, brown-gray, fossiliferous with carbonaceous partings
Top-of-Trenton Unconformity:
Rooney (1966) – southward thinning of Trenton toward Findlay arch in Ohio
DeHaas and Jones (1984,1989) – Exposure and karsting to produce caverns
Keith (1985) and Gray (1983) – dismissed any top-of-Trenton unconformity, considered this surface to be a marine hardground
Black River – Limestone, tan-gray, lithographic; altered to porous dolomite

TRENTON-BLACK RIVER TRAP

Deerfield Field
Lucas-Monroe monocline (extension of Bowling Green Fault Zone)

Northville Field
Faulted anticline

Albion-Scipio Trend and Stoney Point Trend

Stratigraphic traps, limited development of porous, fractured dolomite reservoirs within the tight regional Trenton-Black River limestone northwest-southeast, left-lateral strike slip faulting (en echelon faults) offset 2.5 miles

Reactivated basement faults, primarily Precambrian, w/ additional reactivation during Late Ordovician-Early Silurian?, Late-Silurian-Early Devonian?, Mississippian?

Synclinal sag-like compartments related to down-dropping over partly extensional, en echelon breaks in the underlying section

Diagenetic porosity development (dolomitization) near faults

- Sharp contacts between dolomite and regional limestone
- Albion-Scipio, Stoney Point Fields– no anticlinal closure

TRENTON-BLACK RIVER SEAL

(1) Overlying Utica Shale
(2) Non-porous, finely crystalline, ferron “cap dolomite” at the top of the Trenton Group
(3) Non-dolomitized regional Trenton-Black River limestone
(4) Trace fluorite, sphalerite, barite mineralization observed as late-stage pore fillings

TRENTON-BLACK RIVER CHARACTERISTICS

Porosity

Vuggy, cavernous
Intercrystalline
Open fractures, often solution enlarged
2-5% normal
8-12% present but uncommon

Permeability

Extremely variable (0.01 – 8000 md)
Generally low (85% of samples < 10 md)
Porosity/Permeability plots show no uniform relationship

Capillary Pressure

High entry pressures in cap dolomite (confirms seal)
High entry pressures in Trenton-Black River = moderate to poor reservoir rocks

Log Signatures

Lost circulation – most wells cased and then logged
Gamma ray – neutron log typical
Neutron porosities range 2-10% (4-6% most common)
Modern gamma-ray logs, porosity of 26% observed at Utica Shale baseline
Many wells show < 0% neutron porosity = no cement behind casing

- Base of zone usually at gas/oil contact

Thin shale layers acted as flow barriers during dolomitization, so most
- Reservoirs located below persistent shale layers - particularly true for "E" Shale (Best developed in northern portion of Albion Field) and Black River Shale (Best developed in southern portion of Albion Field)

Typical log – Figure 18 in Hurley and Budros

<u>Fractures</u>

Dominant trend N30W

Secondary trend east-west (Finnigan's Finger north of Haskell Unit)

Open, partially filled, and filled

Filling = saddle dolomite w/ calcite and anhydrite locally present, trace amounts of MVT minerals

<u>Lost Circulation Zones/Caves</u>

Some zones encountered in cap dolomite (seal)

30% of wells in Albion-Scipio encountered lost circulation

54% of wells in Stoney Point encountered lost circulation

Bit drops up to 62' reported in Albion-Scipio - rare

Bit drops up to 8' reported in Stoney Point – rare

DeHaas and Jones (1984, 1989) propose cave development related to karsting responsible for lost-circulation zones; however, few others agree with this relationship due to:

1.) bit drops rare, most zones solution-enlarged fractures or vuggy rock
2.) Trenton-Black River arbitrarily divided into 4 levels w/ no true geological relationship to caves and lost-circulation zones
3.) Synclinal depression across field persists through Early Devonian - Cave formation would collapse under 1500' of overburden
4.) Geochemical data shows reservoir dolomites precipitated from hot solutions, some dissolution porosity is a late-stage event
5.) No cave features such as flowstone, cave sediments, cave pearls observed
6.) Core shows no karst features at Trenton/Utica contact – rather phosphatic and pyritic mineralization suggest a hardground (same as top-of-Trenton contact in Indiana)
7.) If caves formed during Ordovician – then Utica Shale should have filtered down into subsurface and this is not observed.

It appears that Mammoth Cave analog is not correct, rather, lost-circulation zones were probably developed by fracturing and dolomitization in a hydrothermal setting in a burial environment (Hurley and Budros)

RESERVOIR COMPARTMENTS

Determined by:
- Structure Maps
- Fluid Contacts
- Oil and Gas Ratios
- Bottom-hole Pressures
- Lateral Well Drilling Data

Inter-well Scale shows en echelon synclinal compartments

Field Scale shows free gas cap with 150'-200' oil column

Pulaski Break – Major non-dolomitized discontinuity of fluid levels between Albion and Scipio Field

Stoney Point Field – 4 major compartments based on BHP's and decline rates

Albion Field – 3 major compartments based on BHP's and decline rates

Albio, Scipio and Stoney Point Fields – subtle east-west permeability barriers due to fracture zones that have undergone mylonitization and/or pervasive cementation

Finnigan's Finger – east-west production due to incomplete late-stage crystallization

Compartment Boundaries vs. Lost Circulation Zones
- Most lost circulation zones on up-dip (south) side of barriers between Group 2 and 4, and Groups 1 and 2 (Figure 27, Hurley and Budros)
- Lost circulation zone decrease southward in Group 2 Suggesting that dolomitizing fluids move upward along east-west fracture zones
- Dolomites also formed on undersides of shales suggesting upward fluid flow
- Stoney Point - Dolomites/lost circulation zones concentrated in lower part

ORIGIN OF DOLOMITE

1) Burgess (1960) – Reservoir dolomite was a secondary mineral formed as Cambrian and Lower Ordovician water moved up along the fracture zone (analogs- Dover and Colchester Fields in Ontario)

2) Ells (1962) – Magnesium-bearing waters ascending through fractures responsible to dolomitization (Albion-Scipio Field similar to Mississippi Valley-type [MVT] lead-zinc mineral deposits)

3) Beghini and Conroy (1966) – Reservoir formed by pre-Black-River Group water that moved through faults and fractures to produce secondary dolomite

4) Buehner and Davis (1968) – Reservoir is epigenetic dolomite related to a fault system

5) Shaw (1975) – Described a mineral assemblage (including sphalerite) in Albion-Scipio cores similar to MVT mineral deposits. He noted 2-phase fluid inclusions in Albion-Scipio dolomites. Pore filling saddle dolomites precipitated from fluids at minimum of 80 degree C temperature. He identified a liquid-hydrocarbon phase in some fluid inclusions indicating hydrocarbons were present at time of cementation. Proposed a model of replacement dolomitization and development of intercrystalline porosity during Middle to Late Silurian by waters percolating through fractures. Magnesium is sourced from underlying Prairie du Chien dolomite or Trempealeau formations. Second phase - during Lower to Middle Devonian as hot fluids from basin center created cavernous porosity, subsequent collapse, and precipitation of MVT assemblage.

6) Ardrey (1978), DeHaas and Jones (1984, 1989) Diagenesis of Trenton-Black River in Albion-Scipio area due to exposure (top of Trenton Unconformity). Dolomitization is the result of mixing models based on the observation that Trenton formation water is less saline than water in shallower horizons; therefore, it could not be of hydrothermal origin.

7) Taylor and Sibley (1986) – They identified 3 major types of dolomite (1) regional dolomite not associated with Field, (2) Cap dolomite that occurs in the top 40 feet (related to interaction of the Trenton with Fe-rich fluids formed during the de-watering of the overlying Utica Shale) (3) fracture-related dolomite (formed during deeper burial at approximately 80 degrees C based on geochemical results)

8) Budai and Wilson (1986) – They identified various MVT accessory minerals including pyrite, calcite, anhydrite, barite, celestite, sphalerite, and fluorite in association with saddle dolomite cements. They proposed a hydrothermal model with Paleozoic and Precambrian basement rock as sources of iron, sulfur, and other trace metals.

9) Hurley and Cumella (1987) – They proposed a model based on carbon, oxygen, and strontium isotopes fluid-inclusion geothermometry, brine geochemistry and regional hydrologic constraints. Dolomitizing fluids were Silurian-Devonian hypersaline sea water that moved down fracture zones to meet with hot limestone-dissolving fluids moving up from the basement. These fluids mixed in a pattern that is consistent with the distribution of dolomite reservoirs and lost-circulation zones.

SOURCE ROCK

Trenton Black River Sequence is the primary source
- Shaley layers have TOC's 20-25 wt%
- Burial history indicates maturity reached in the Carboniferous for the central basin area

TAI (visual kerogen) and pyrolysis (Tmax) indicate thermally maturity for oil and gas
Utica Shale (above Trenton – traditionally considered source) – TOC's too low

HYDROCARBONS

Paraffinic
41-43 degree API
0.0.02% Sulfur
0.974 cp Viscosity (at reservoir conditions)
GOR's – 400 – 600 scf/STB
Cloud Point – 70 degree F
Free gas cap at time of discovery

WATER CHARACTERISITCS

Connate water dense, CA-rich brine
North of Albion - 234,000 mg/L Total dissolved solids
South of Scipio – 196,000 mg/L Total dissolved solids
Formation water resistivity approximately 0.03 ohm-m at 104 degree F (BHT)

RECOVERY MECHANISMS

Original Recovery
- Solution-gas drive
- Gas cap expansion
- Gravity drainage
- Limited water drive

Current Recovery
- Stoney Point Field – Pressure is still high (approximately 1100 psig)
- Albion-Scipio Field
  - Pressures down to 100-150 psig
  - Gravity drainage now main mechanism

Volumetric Calculations meaningless – unable to accurately estimate porosities
Material Balance Calculations suggest:
- Scipio Field – 170 MMB OOIP
- Albion Field – 120 MMB OOIP
- Stoney Point Field – Not Available

Secondary Recovery
- Pilot Waterflood of the Haskell Unit (near south end Scipio Field) – discouraging results
- Marathon Oil – drilled a number of horizontal wells with considerable promise

EXPLORATION TECHNIQUES

Originally - Advice of psychic after dry hole exploring for Devonian gas
Early - "Trendology"
  Linear Fracture Zone (northwest – southeast)
  Top-of-Trenton synclinal sag (up to 60') recognized in producing wells
1960's - early 70's – Gravity defined basement fault along Scipio Trend
  Limited drilling success
  Dolomite porosity mutes density contrast between regional limestone and reservoir Dolomite
1970's - Magnetics used to detect basement discontinuities and faults
  Albion-Scipio does not appear as an individual feature on magnetic maps
Recently – Micromagnetic surveys and resistivity profiles have been employed
    Significance not yet proven
  Reflection-seismic currently the primary method – Problems:
    Variable till (overburden) thicknesses produce noise and statics problems
    Secondary porosity (dominant reservoir component) not detected by P-waves
    Reservoir dolomites (2-5% porosity) have similar acoustic impedance as regional limestones
    Reservoir geometries hard to image
  Reflection-seismic Trenton-Black River discoveries based on
    Disruptions (sags) at Trenton event
    Internal waveform changes
    Disruption of lower events
    Recognition of faults from offsetting events and/or diffractions
Soil gas geochemistry studies above Scipio field showed no correlation between soil gas and producing parts of the field (despite Stoney Point Field discovery)
LANDSAT – effective as a regional tool but interpretations of individual anomalies subjective
Stoney Point Field - Soil-gas geochemistry

DEVELOPMENT

Albion-Scipio Trend
  Initial Maximum Allowable 150 BOPD and/or 200MCFGPD
  7/1/60 - Maximum Allowable reduced to 125 BOPD and/or 165 MCFGPD
  7/1/61 - Maximum Allowable reduced to 100 BOPD and/or 150 MCFGPD
    (applies only to wells drilled in center of NW qtr of SE qtr of 40 acre unit
  Current – Oil allowable lifted, gas allowable 150 MCFGPD
  Developed on 20 acre spacing
  Decline rate 15% per year
Stoney Point Trend

Maximum Allowable 150 BOPD and/or 175 MCFGPD
Drilling window maximum is 10 acres per 40-acre unit
Developed on 40 acre spacing
Decline rate 15% per year

Subsurfacing mapping useful as development tool

% dolomite in Trenton-Black River sequence
Hydrocarbon shows in Trenton-Black River sequence
Isopach Traverse Limestone (Devonian) to top of Salina Group (Silurian) showing thick of synclinal sag over productive part of field

Trenton – Black River Trend: Production Analysis

General Observations

1. Production data for the Trenton – Black River trend varies in quality and completeness. The State of Michigan did not require complete production data reporting until xxx. Digital data bases developed by the state beginning in 1981 generally do not include data before that date or data before and after that date may be cataloged in different groupings.

2. Production data are often grouped by lease hold and not necessarily by either individual well or by geological producing unit (e.g. – Albion Scipio 1 – 7 South Units). There is no means to separate the data and recalculate results based upon more geologically based, flow-unit parameters.

3. Initial potential data was never recorded for most wells in the trend. Only long-term and/or average data are available in most instances. Data is often duplicated as leasehold results and trend summaries. However, it is seldom clear as to exactly what data are included.

4. The State of Michigan imposes a 200 barrel-per-day maximum allowable on production which often distorts the true capabilities/performance of the affected wells.

5. During the beginning stages of field development, many operators produced the oil and flared the gas. Complete gas production data were only recorded during the later stages of field development as oil production declined and the gas cap was blown down to extend the economic life of the field.

6. Graphs of "Cumulative Oil and Cumulative Gas Production by Field" show an expected exponential decline in field size. "Gaps" in the curve are "filled" by "trend data" which give a distorted view as to the particular field sizes discovered. When these trends are omitted (difficult to accurately identify) a pattern emerges showing a few very large fields discovered (Albion-Scipio Trend), a large number of 1-5 well size fields discovered, and only a few intermediate field sizes discovered. Dr. Christopher Swezey of the U.S.G.S. interprets this to mean that there are still intermediate sized Trenton-Black River fields to be found. He calculates that as much as 723 million barrels of oil, 2,002 billion cubic feet of gas, and 112 million barrels of NGL's may yet remain. The play is not resource limited as much as it is technology limited. It represents the greatest single remaining potential reserves for a particular reservoir in the State of Michigan.

7. Most fields have produced more oil than gas. However, there are 5 fields in the trend that have produced more gas than oil. These are: Albion-Pulaski-Scipio Trend, Albion-Scipio 3 South, Albion-Scipio 4 South, Albion-Scipio 5 South, and Northville.

8. Only Stoney Point field has produced more brine (bbls) then gas (BOE).

9. Cumulative Oil Production can be divided into approximately 5 main groups:
   a.) **<u>>10,000,000 bbls</u>**
      Albion-Pulaski-Scipio Trend, Scipio-Fayette-Moscow, Stoney Point, Pulaski-Homer Twp, Albion Twp.
   b.) **<u>500,000 – 6,000,000 bbls</u>**
      Adams Twp, Sheridan Twp, Lee Twp, Hanover, Albion-Scipio 6 South, Albion-Pulaski-Scipio Trend, Albion-Scipio 5 South, Northville, Dearfield, Albion-Scipio 3 South, Albion-Scipio 4 South
   c.) **<u>5,000 – 50,000 bbls</u>**
      Albion-Scipio 2 South, Reading Section 25, Albion-Scipio 1 South, Northville?, Henrietta, Tekonsha,Lee Section 34 (Black River), Freedom, Reading, Medina, Springport, Green Oak
   d.) **<u>500 – 5,000 bbls</u>**
      Rattle Run, Summerfield, Albion-Scipio 7 South, Huron, Hanover Section 13, Summerfield Section 07, Macon Creek, Summerfield Section 19, Blissfield, New Boston, Newburg, Cadmus, Olivet, Sumpter
   e.) **<u>0 - 60 bbls</u>**
      Ridgeway Section 01, Winterfield

10. Cumulative Gas Production can be divided into approximately 5 groups:
   a.) **<u>>100,000,000 MCF</u>**
      Albion-Pulaski-Scipio Trend
   b.) **<u>6,000,000 – 100,000,000 MCF</u>**
      Scipio-Fayette-Moscow Trend, Pulaski-Homer Twp, Stoney Point, Albion Twp, Northville, Albion Scipio 4 South
   c.) **<u>1,000,000 – 6,000,00 MCF</u>**
      Adams Twp, Albion Scipio 5 South, Albion-Pulaski-Scipio Trend, Albion Scipio 3 South, Reading Section 3 South, Reading Section 25, Albion Scipio 1 South, Albion Scipio 6 South, Sheridan Twp
   d.) **<u>300,000 – 1,000,000 MCF</u>**
      Albion Scipio 2 South, Hanover, Lee Section 34 (Black River), Lee Twp
   e.) **<u>50,000 – 300,000 MCF</u>**
      Cadmus, Winterfield, Green Oak, Blissfield

11. There is little correlation between “Years of Production” vs. “Cumulative Oil Production by Field” or “Year of Discovery.” Longest producing fields (most years of production) range from discovery dates of 1935 (Deerfield), 1947 (New Boston), 1954 (Northville), 1961Springport, and 1967 (Green Oak). However, these fields do not reflect the greatest cumulative oil totals. Instead, accumulations from these fields are similar to those from fields having produced for the fewest years (Reading Section 25 – disc 1999, Henrietta – disc 1979, Albion-Pulaski-Scipio Trend – disc 1981). Fields reflecting “Maximum Oil Accumulation” are associated with “Years of Production” intermediate in range (Scipio-Fayette-Moscow Trend – disc 1957, Albion Twp – disc 1959, Albion-Pulaski-Scipio Trend – disc 1960, Pulaski-Homer Twp – disc 1959, Stoney Point – disc 1984, Albio-

Scipio6 South – disc 1982, Adams Twp – disc 1967, Sheridan Twp – disc 1967). The lack of correlation between "Years of Production," "Cumulative Oil Production by Year" and "Year of Discovery" leads one to speculate that fields of varying reservoir types and production capabilities, overprinted by the learning curve of discovery, have been mixed into a single data base. Approximately four groups can be identified within this data base:

(1) > 30 years of production; Deerfield, Northville, Springport, New Boston,

(2) 20 – 30 years of production; Green Oak, Freedom, Ridgeway Section 01, Summerfield, Albion-Scipio 1 South, Albion Scipio 3 South, Hanover, Scipio-Fayette-Moscow, Tekonsha, Albion Twp, Albion-Pulaski-Scipio Trend, Macon Creek, Medina, Pulaski-Homer Twp, Stoney Point,

(3) 10 – 20 years of production; Blissfield, Lee Section 34 (Black River), Albion Scipio 2 South, Albion Scipio 5 South, Cadmus, Albion Scipio 6 South, Northville, Albion Scipio 4 South, Adams Twp, Lee Twp, Olivet, Sheridan

(4) 0 – 10 years of production; Reading, Albion Scipio 7 South, Summerfield Section 19, Winterfield, Rattle Run, Reading Section 25, Summerfield Section 07, Huron, Henrietta, Newburg, Sumpter, Albion-Pulaski-Scipio Trend, Hanover.

12. There appear to be four distinct groups of "Field Size" in comparison to "Year Discovered."

(1) 1935 -1960; Deerfield, Sumpter, Huron, New Boston, Freedom, Northville, Ridgeway Section 01, Scipio-Fayette-Moscow Twp, Summerfield, Albion Twp, Hanover, Pulaski-Homer Twp, Tekonsha, Albion-Pulaski-Scipio Trend,

(2) 1960 – 1967; Macon Creek, Medina, Springport, Blissfield, Adams Twp, Green Oak, Lee Twp, Sheridan Twp,

(3) 1969 – 1984; Olivet,, Reading, Henrietta, Newburg, Albion Scipio 1 – 6 South, Northville (Gas Storage), Albion Scipio 7 South, Stoney Point,

(4) 1985 – 1999; Winterfield, Cadmus, Lee Section 34 (Black River), Rattle Run, Hanover Section 13, Summerfield Section 07, Summerfield Section 19, Reading Section 25. Each group displays a general trend of increasing field size through time. This "re-setting of the curve" may reflect discovery of differing field types followed by increasing knowledge of how to explore and develop these new types.

13. Nearly one-half of the Trenton – Black River fields produce only oil (Albion-Scipio 7 South, Deerfield, Freedom, Henrietta, Macon Creek, Medina, New Boston, Newburg, Northville, Olivet, Reading, Ridgeway Section 01, Springport, Summerfield,

Summerfield Section 07, Summerfield Section 19, Tekonsha, Hanover Section 13, Huron, Rattle Run, Sumpter) .

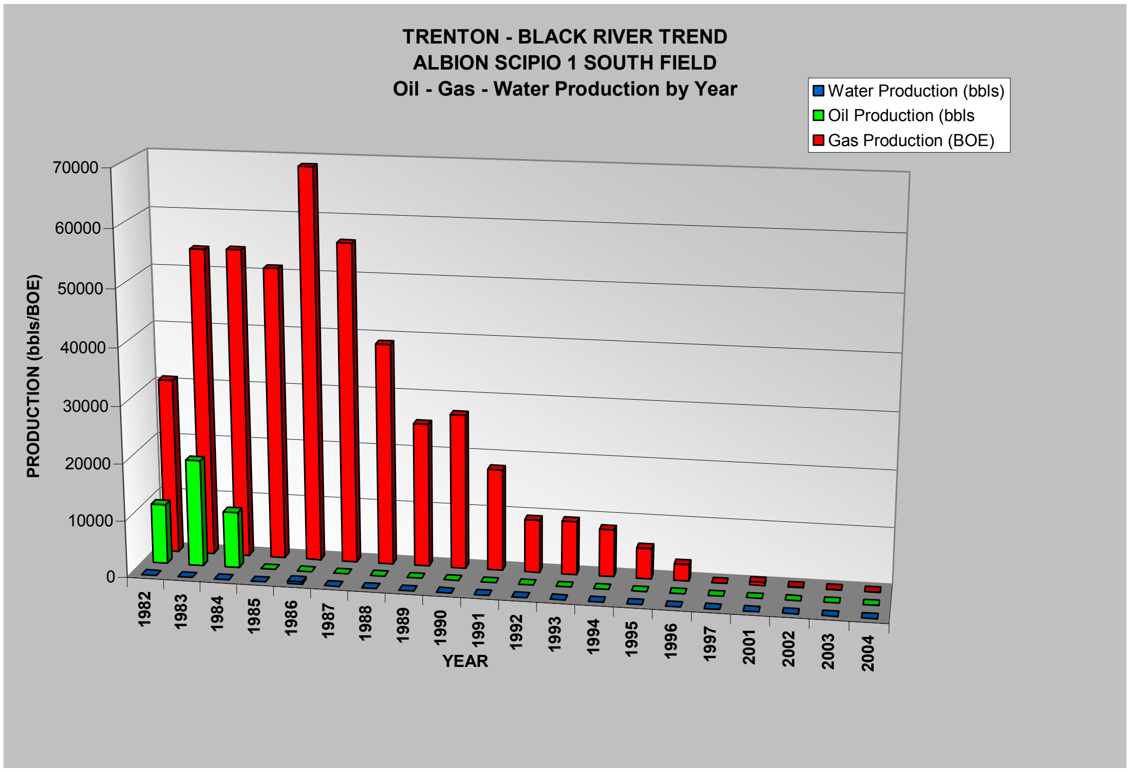
14. The other half of the Trenton – Black River fields produce both oil and gas (Albion-Pulaski-Scipio Trend, Scipio-Fayette-Moscow, Pulaski-Homer Twp, Stoney Point, Albion Twp, Northville, Albion-Scipio 1-6 South, Adams Twp, Reading Section 28, Sheridan Twp, Hanover, Lee Section 34 (Black River), Lee Twp, Cadmus, Winterfield, Green Oak, Blissfield) .

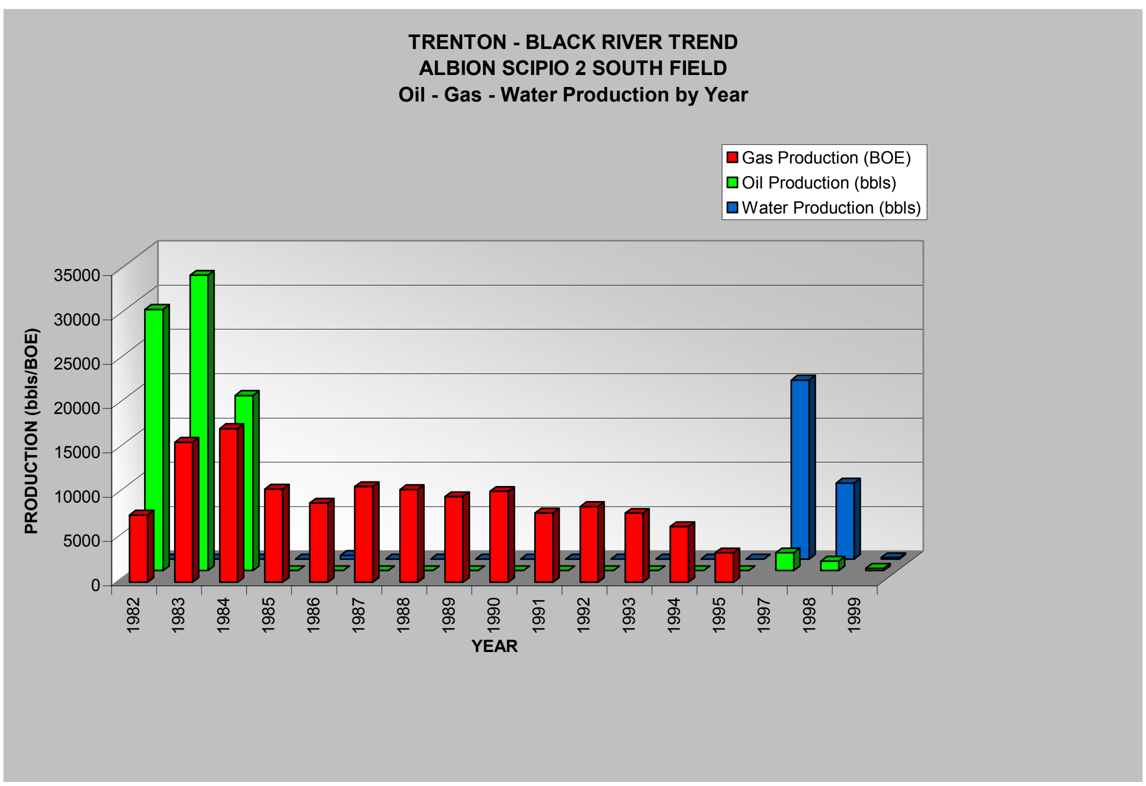
15. Winterfield is the only field in the trend to produce only gas. This is primarily a Dundee Formation field producing both oil and gas from that interval. Only one well in the field penetrates the deeper Trenton – Black River Formations producing gas from those intervals.

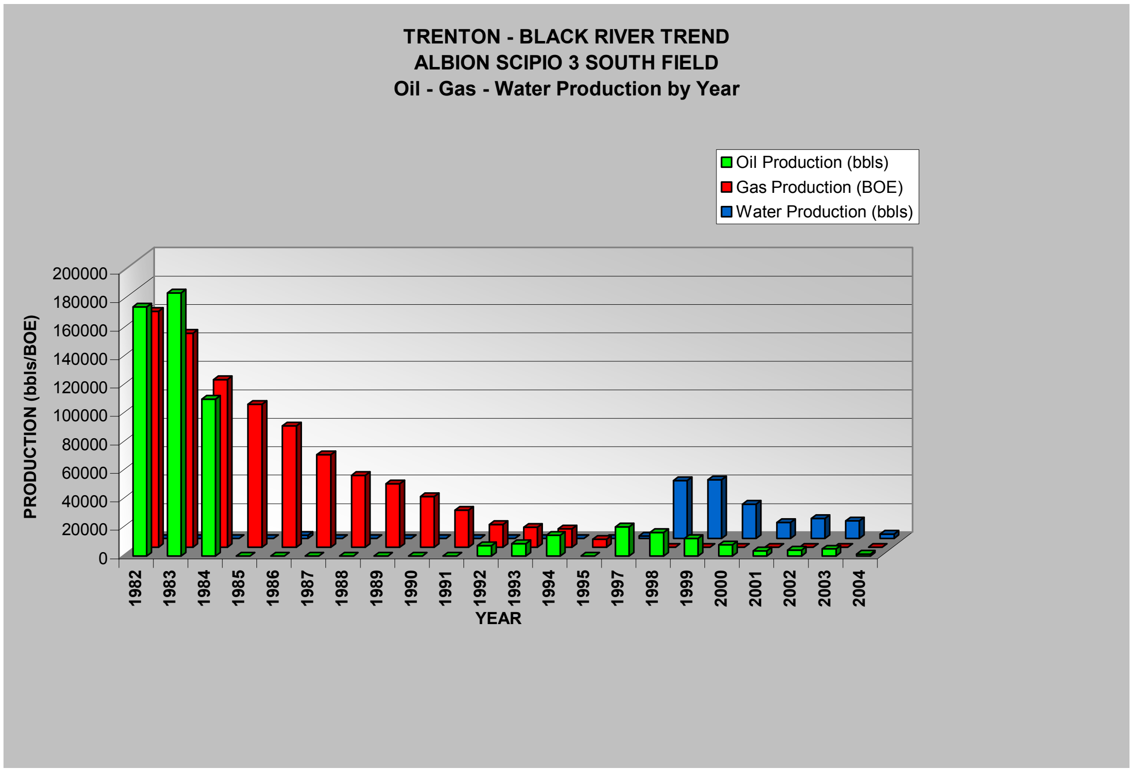
Current Activity

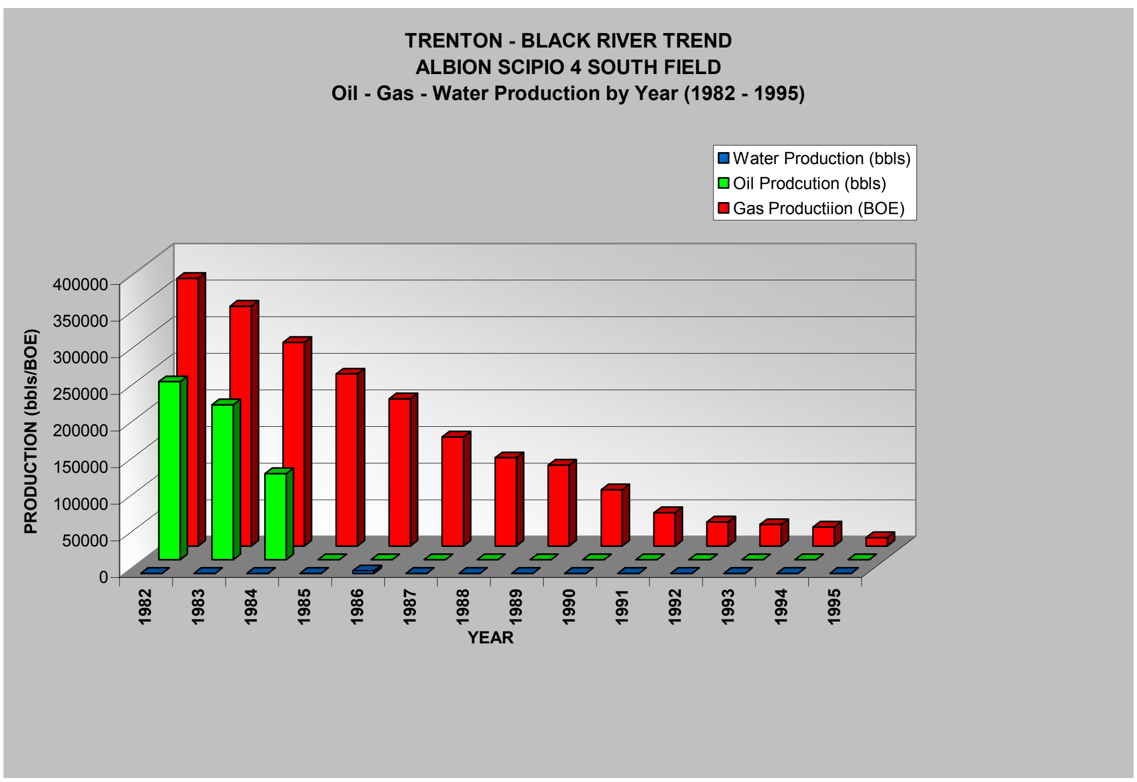
Data from the first 4 years of the Albion – Scipio field which are contained in the Albion – Scipio Field Folio Series is currently being entered into a computer data base. These data are lease based and reported upon a monthly schedule. It is thought that these data more accurately reflect initial production conditions and are more consistently reported. These data will be analyzed when data entry is complete.

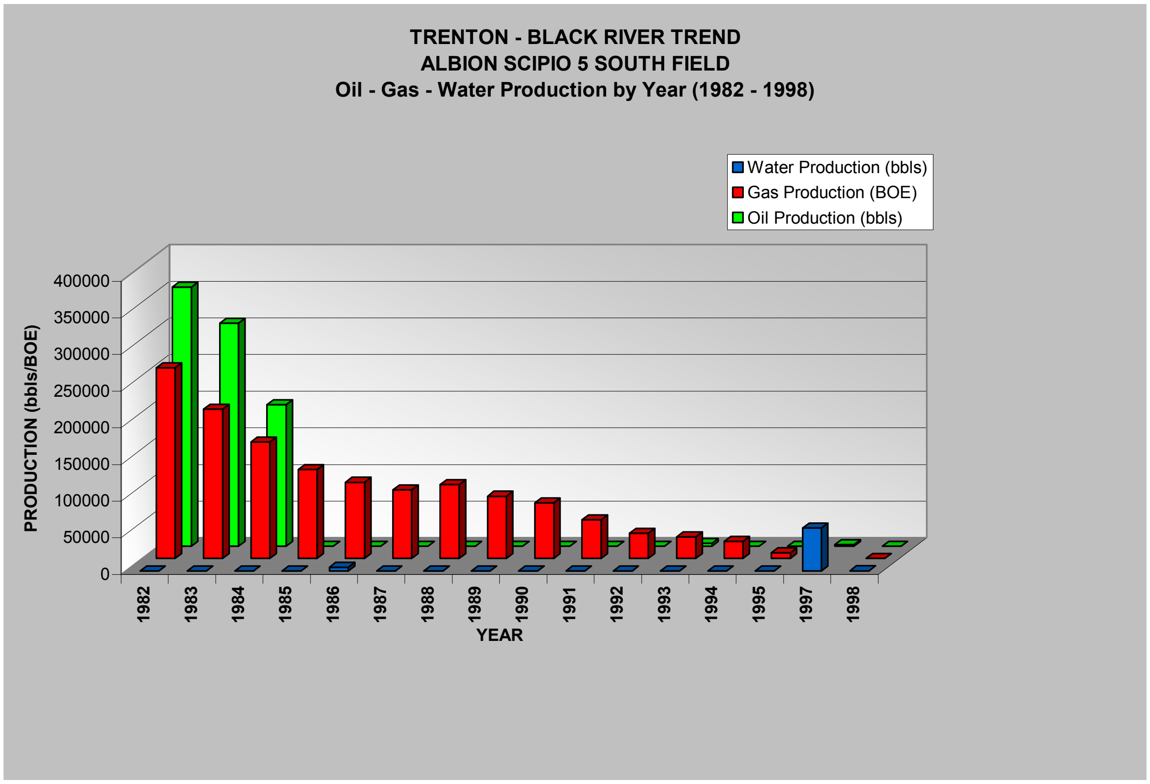
1. Fields from each category defined above will be correlated to the newly developed index covering data quantity, quality and availability for each field. Fields in each category ranking high in data coverage will be selected for detailed study.

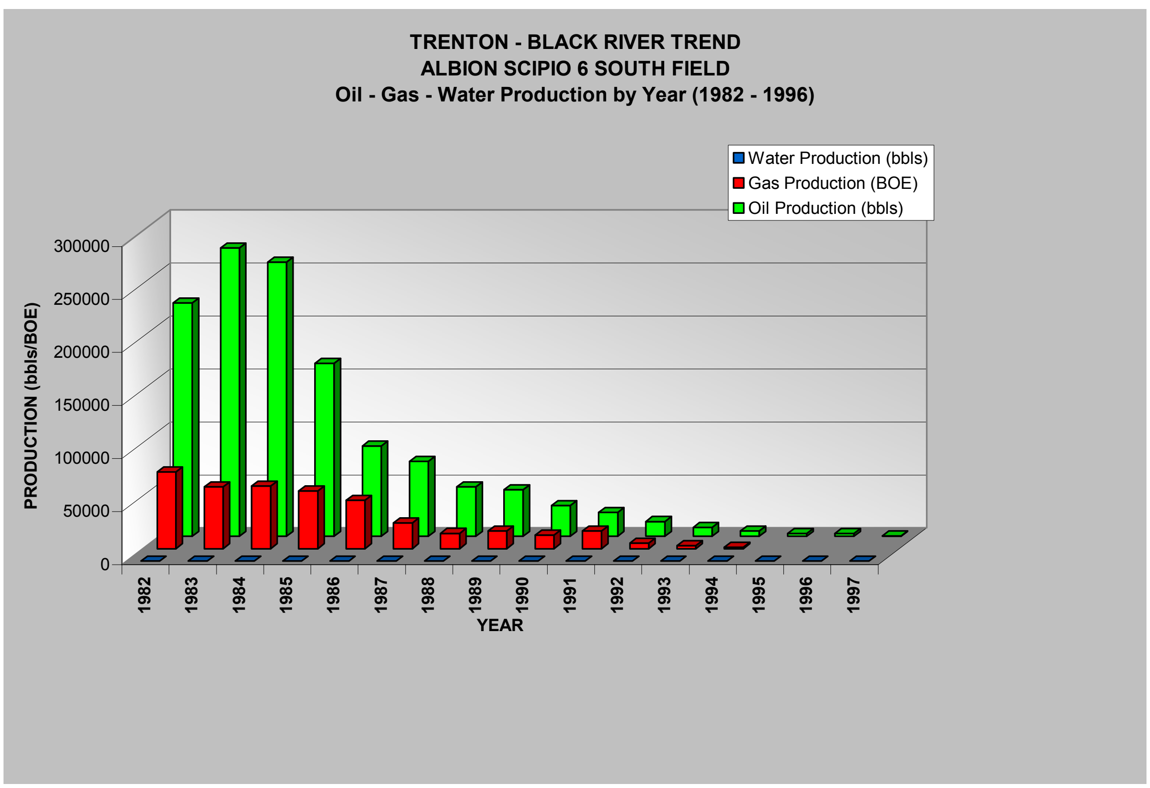

TRENTON - BLACK RIVER TREND
ALBION SCIPIO 1 SOUTH FIELD
Oil - Gas - Water Production by Year
Water Production (bbls)
Oil Production (bbls
Gas Production (BOE)
PRODUCTION (bbls/BOE)
70000
60000
50000
40000
30000
20000
10000
0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
2001
2002
2003
2004
YEAR

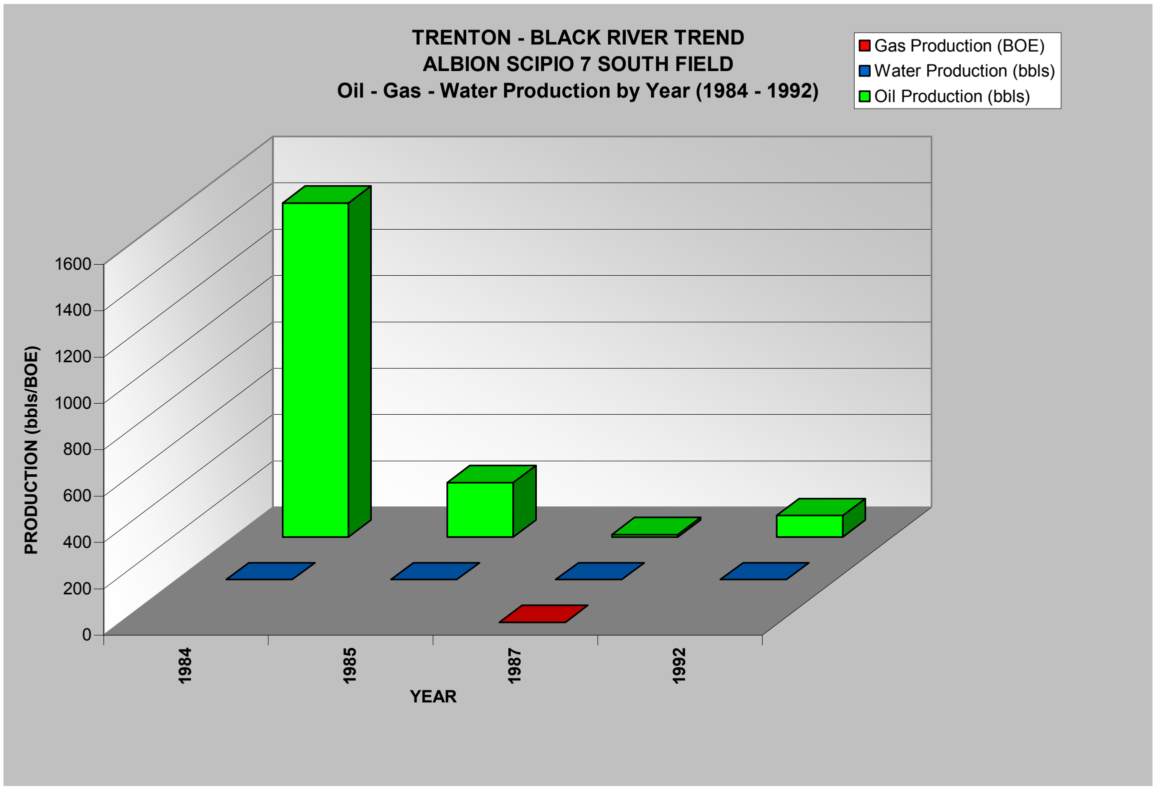

TRENTON - BLACK RIVER TREND
ALBION SCIPIO 2 SOUTH FIELD
Oil - Gas - Water Production by Year
Gas Production (BOE)
Oil Production (bbls)
Water Production (bbls)
PRODUCTION (bbls/BOE)
35000
30000
25000
20000
15000
10000
5000
0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1997
1998
1999
YEAR

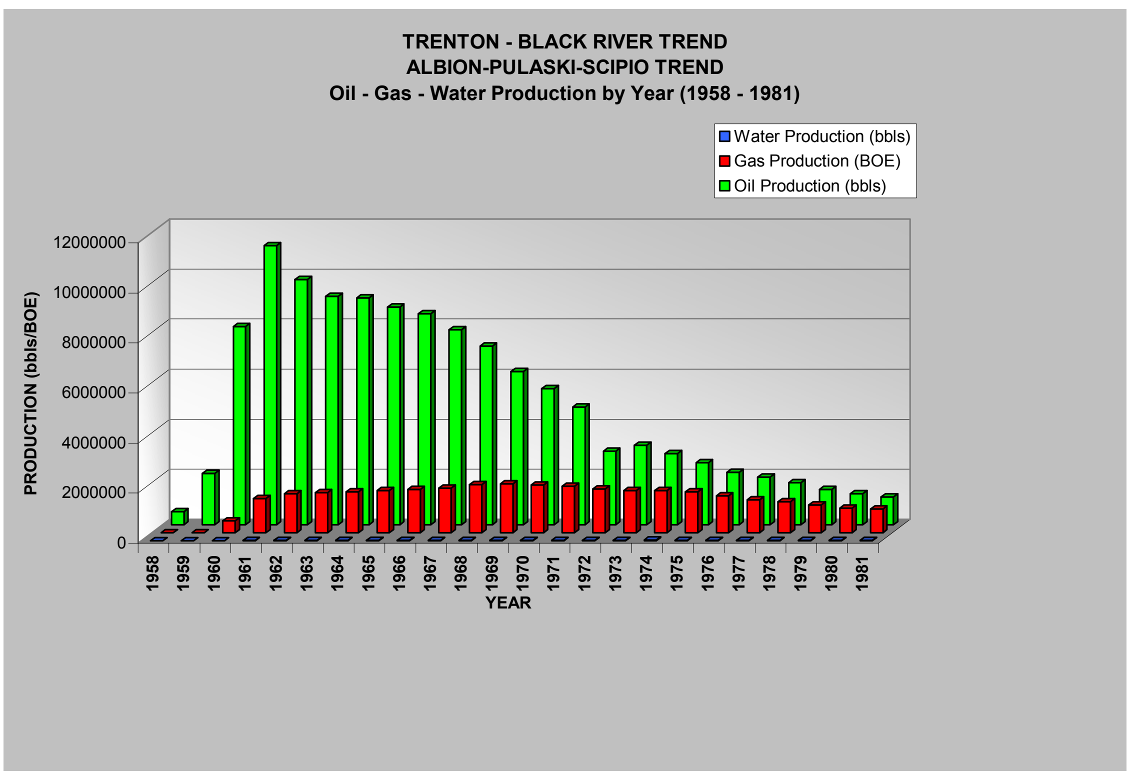

TRENTON - BLACK RIVER TREND
ALBION SCIPIO 3 SOUTH FIELD
Oil - Gas - Water Production by Year
Oil Production (bbls)
Gas Production (BOE)
Water Production (bbls)
PRODUCTION (bbls/BOE)
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1997
1998
1999
2000
2001
2002
2003
2004
YEAR

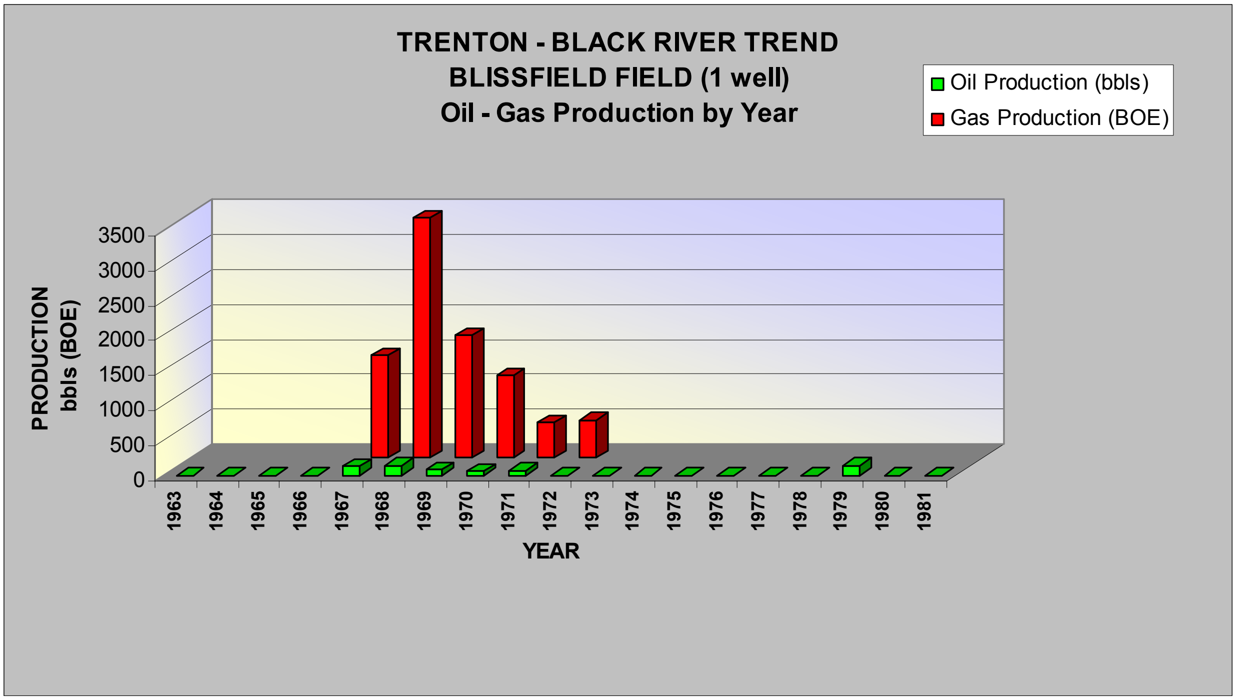

TRENTON - BLACK RIVER TREND
ALBION SCIPIO 4 SOUTH FIELD
Oil - Gas - Water Production by Year (1982 - 1995)
Water Production (bbls)
Oil Prodcution (bbls)
Gas Productiion (BOE)
PRODUCTION (bbls/BOE)
400000
350000
300000
250000
200000
150000
100000
50000
0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
YEAR

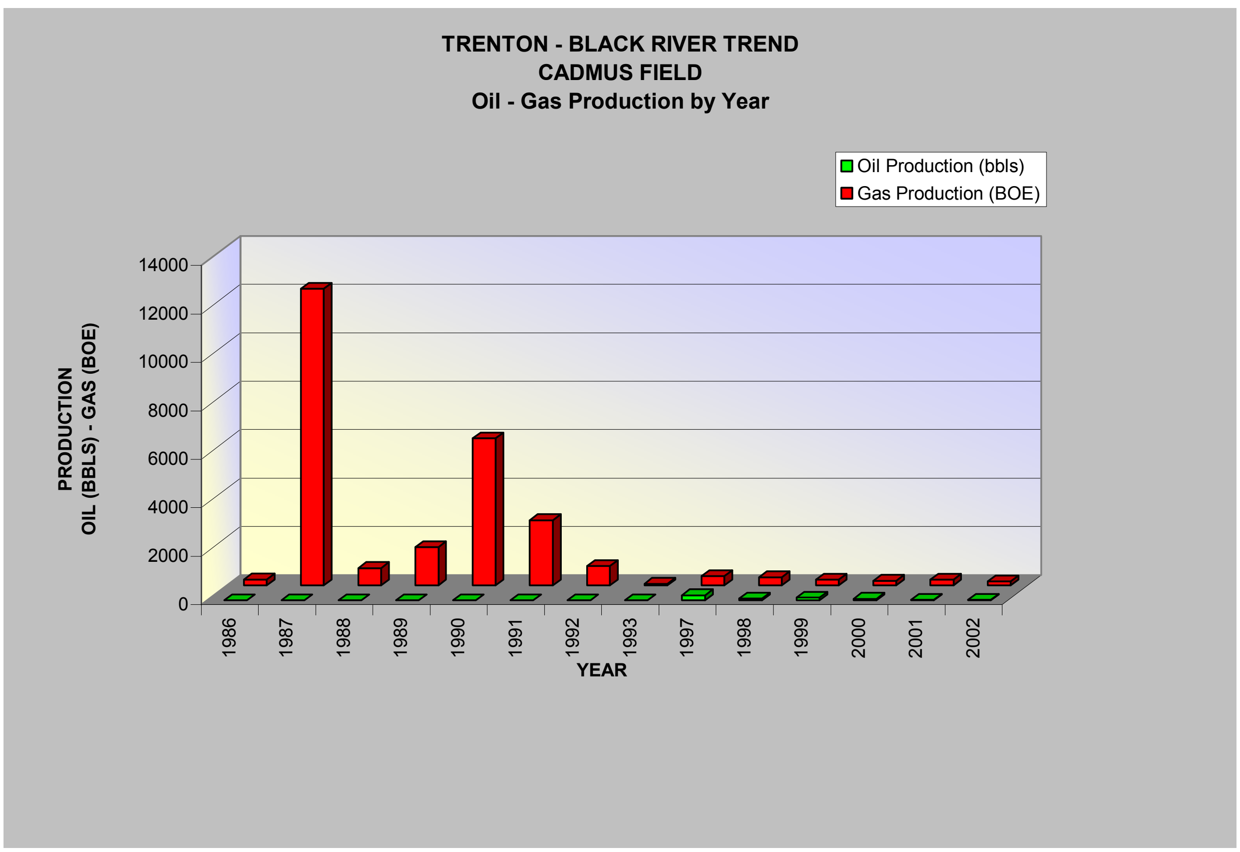

TRENTON - BLACK RIVER TREND
ALBION SCIPIO 5 SOUTH FIELD
Oil - Gas - Water Production by Year (1982 - 1998)
Water Production (bbls)
Gas Production (BOE)
Oil Production (bbls)
PRODUCTION (bbls/BOE)
400000
350000
300000
250000
200000
150000
100000
50000
0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1997
1998
YEAR

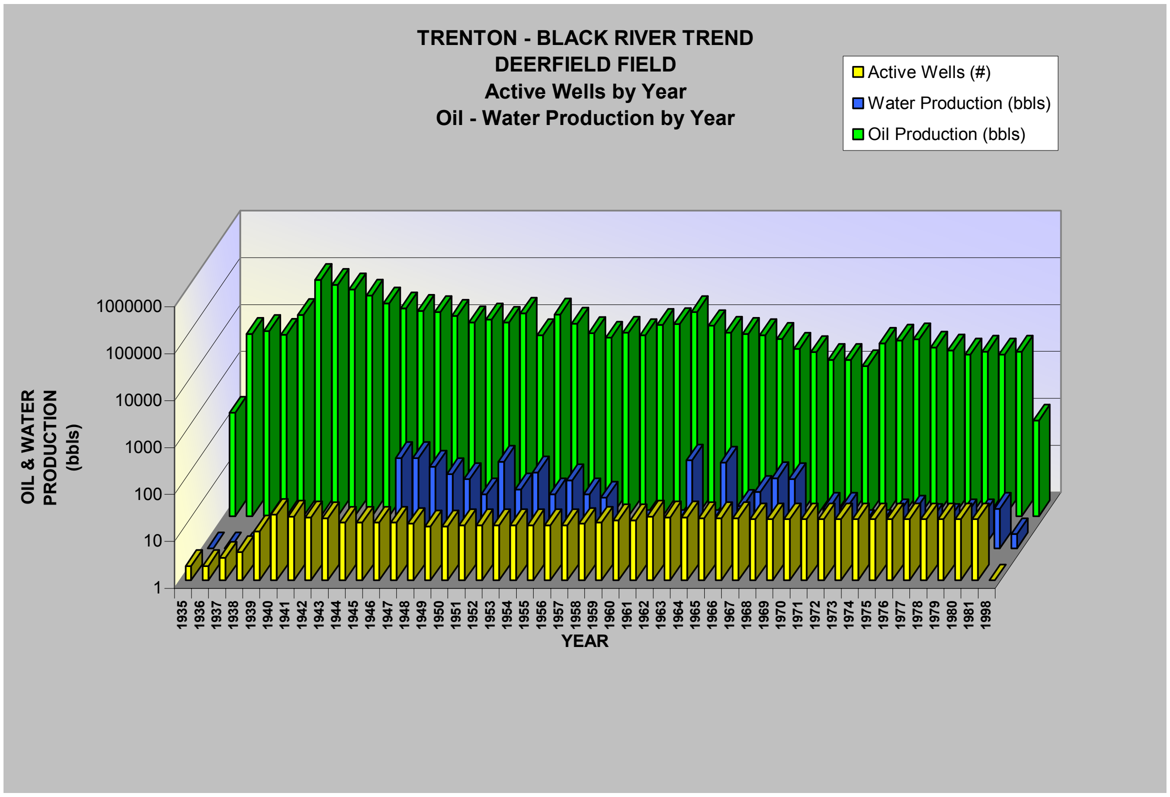

TRENTON - BLACK RIVER TREND
ALBION SCIPIO 6 SOUTH FIELD
Oil - Gas - Water Production by Year (1982 - 1996)
Water Production (bbls)
Gas Production (BOE)
Oil Production (bbls)
PRODUCTION (bbls/BOE)
300000
250000
200000
150000
100000
50000
0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR

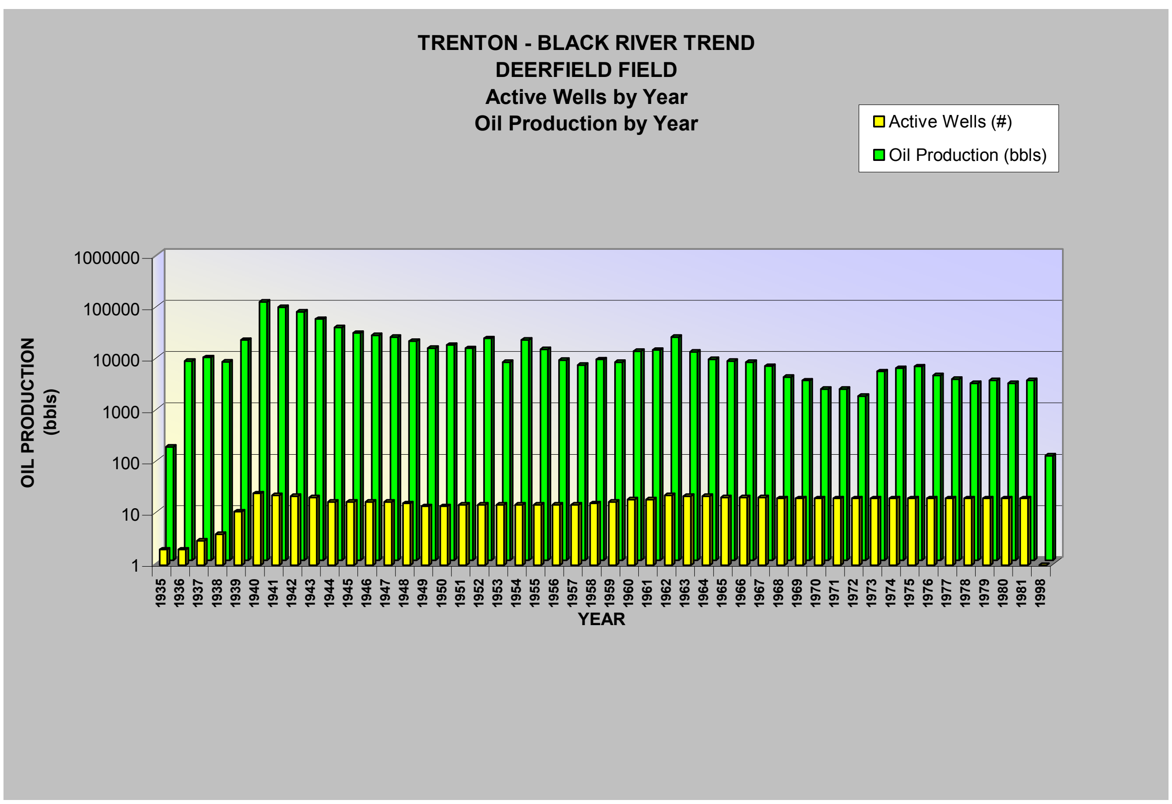

TRENTON - BLACK RIVER TREND
ALBION SCIPIO 7 SOUTH FIELD
Oil - Gas - Water Production by Year (1984 - 1992)
Gas Production (BOE)
Water Production (bbls)
Oil Production (bbls)
PRODUCTION (bbls/BOE)
0
200
400
600
800
1000
1200
1400
1600
1984
1985
1987
1992
YEAR

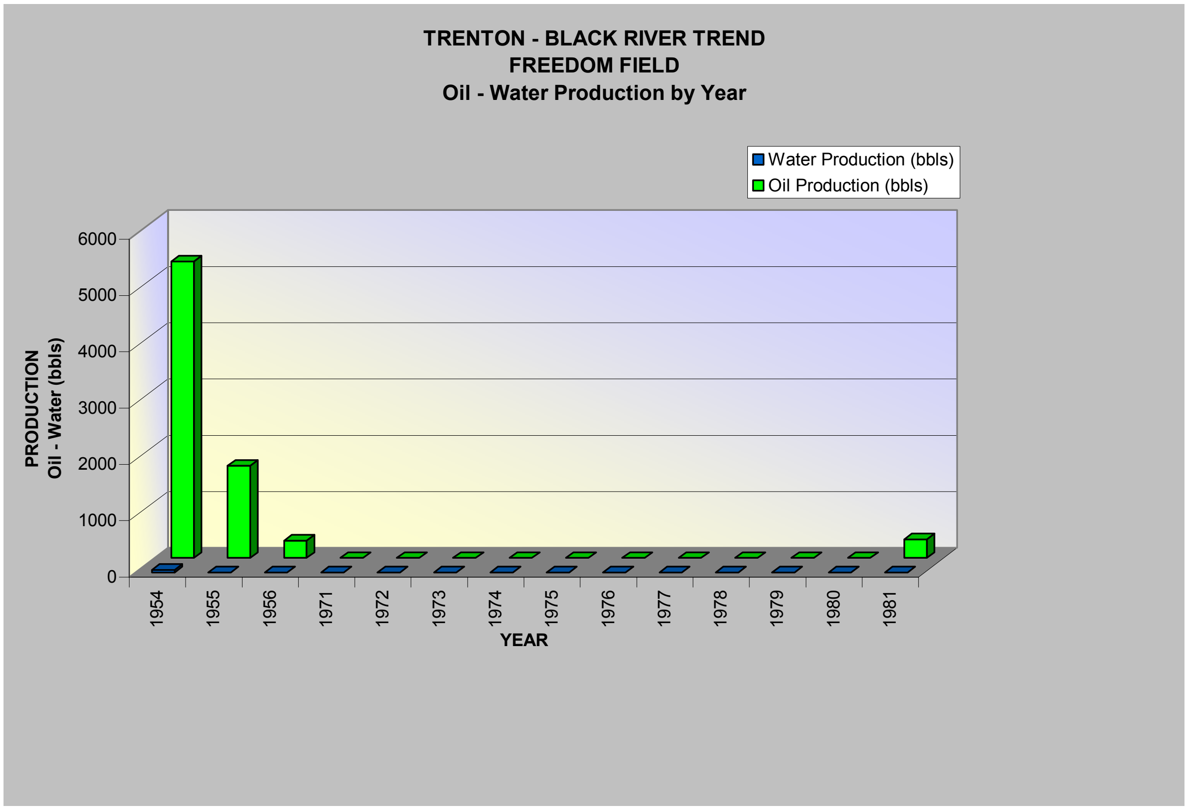

TRENTON - BLACK RIVER TREND
ALBION-PULASKI-SCIPIO TREND
Oil - Gas - Water Production by Year (1958 - 1981)
Water Production (bbls)
Gas Production (BOE)
Oil Production (bbls)
PRODUCTION (bbls/BOE)
0
2000000
4000000
6000000
8000000
10000000
12000000
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
YEAR

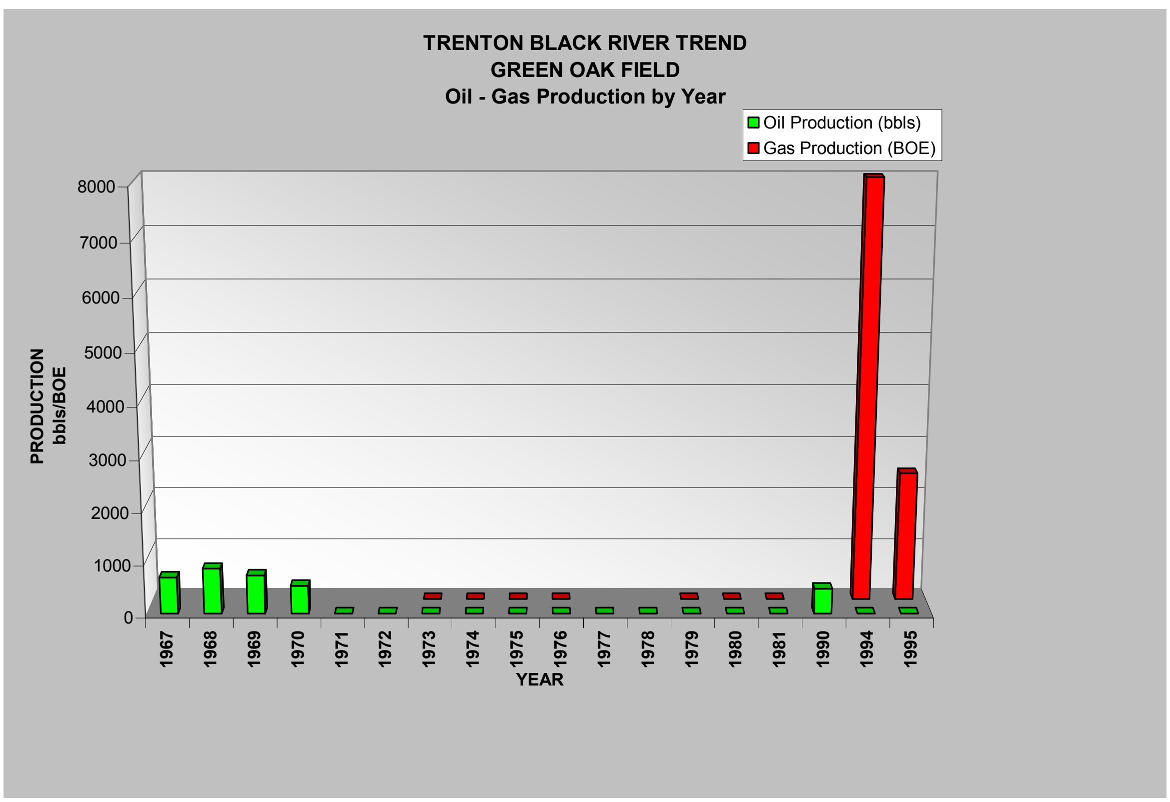

TRENTON - BLACK RIVER TREND
BLISSFIELD FIELD (1 well)
Oil - Gas Production by Year
Oil Production (bbls)
Gas Production (BOE)
PRODUCTION
bbls (BOE)
3500
3000
2500
2000
1500
1000
500
0
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
YEAR

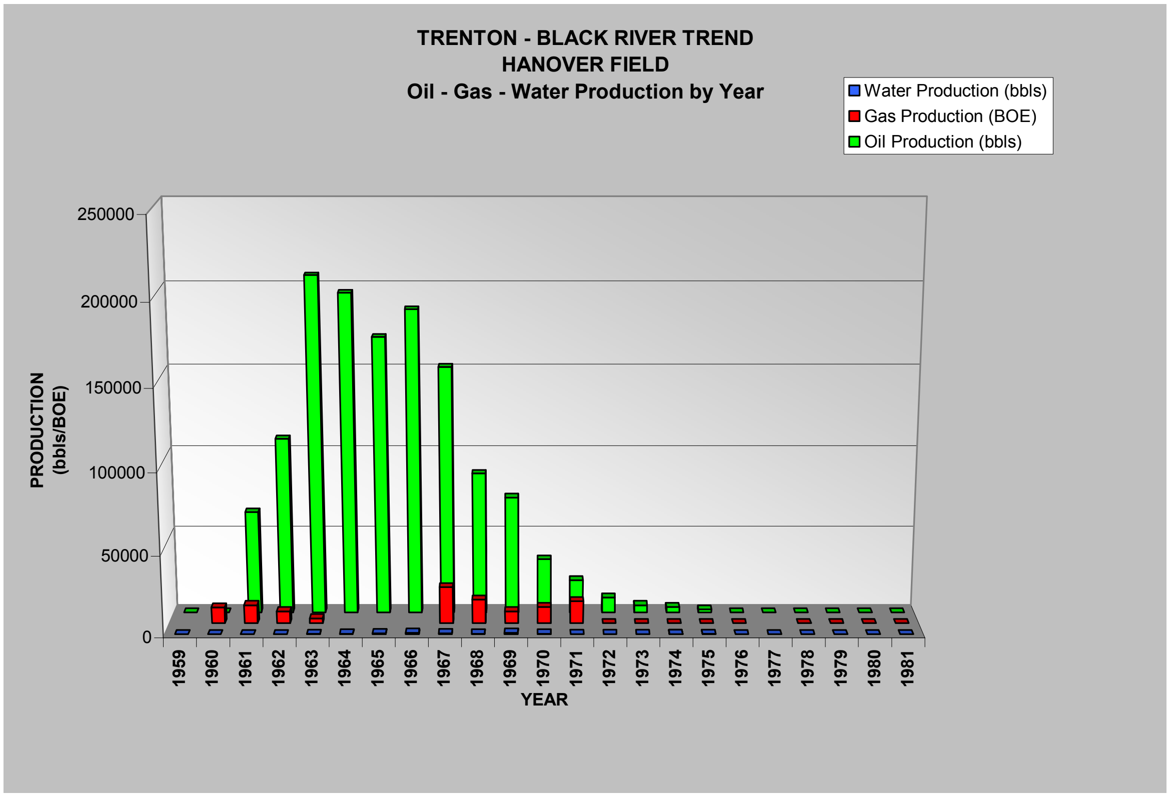

TRENTON - BLACK RIVER TREND
CADMUS FIELD
Oil - Gas Production by Year
Oil Production (bbls)
Gas Production (BOE)
PRODUCTION
OIL (BBLS) - GAS (BOE)
14000
12000
10000
8000
6000
4000
2000
0
1986
1987
1988
1989
1990
1991
1992
1993
1997
1998
1999
2000
2001
2002
YEAR

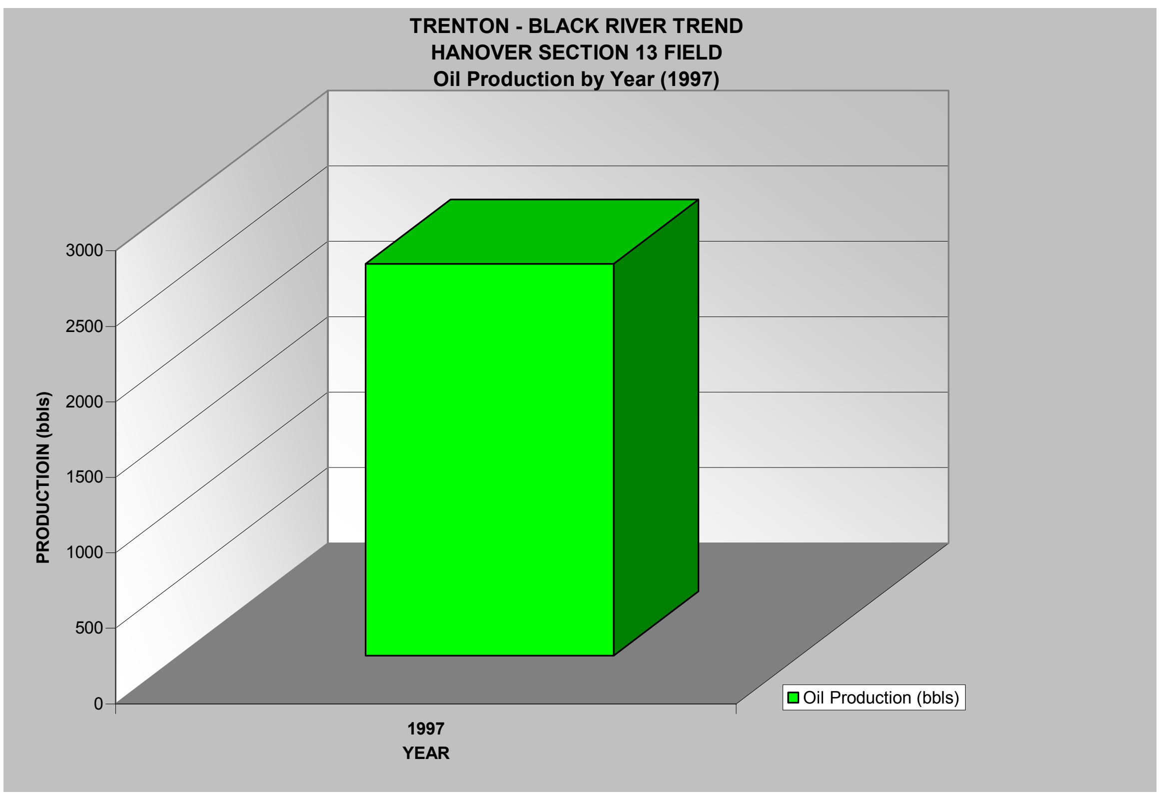

TRENTON - BLACK RIVER TREND
DEERFIELD FIELD
Active Wells by Year
Oil - Water Production by Year
Active Wells (#)
Water Production (bbls)
Oil Production (bbls)
OIL & WATER PRODUCTION (bbls)
1000000
100000
10000
1000
100
10
1
YEAR

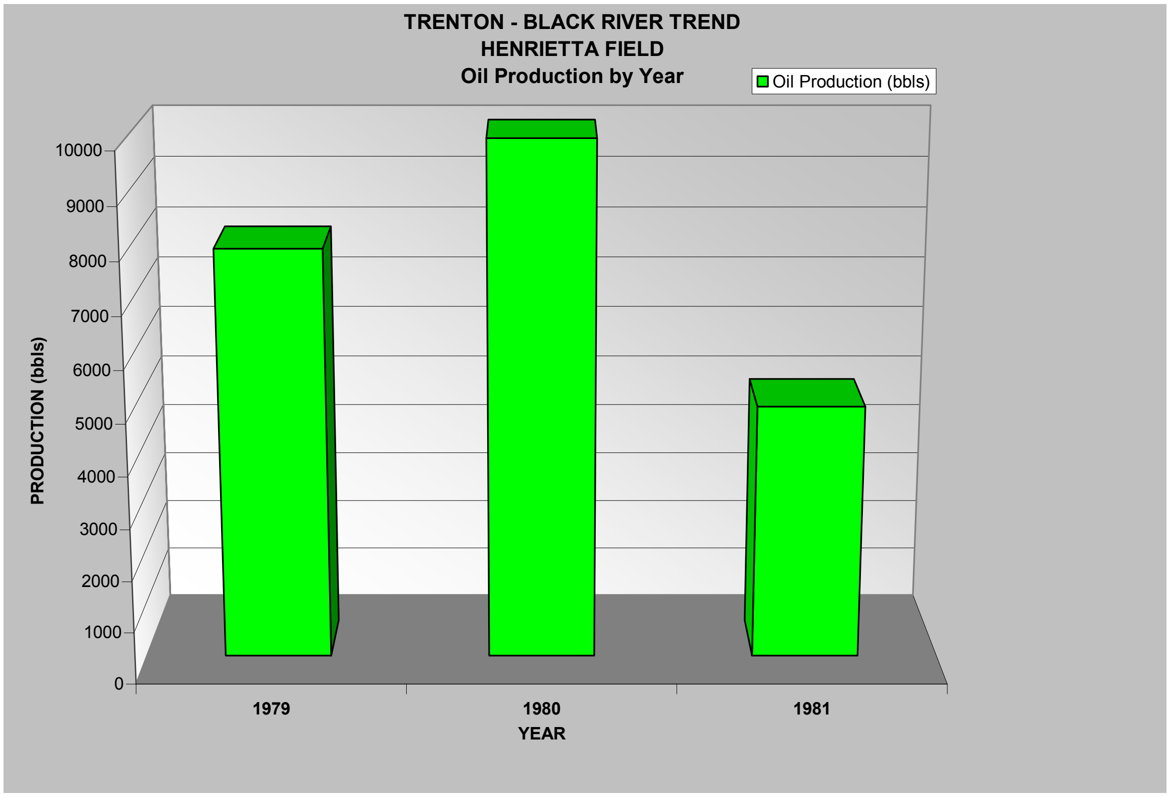

TRENTON - BLACK RIVER TREND
DEERFIELD FIELD
Active Wells by Year
Oil Production by Year
Active Wells (#)
Oil Production (bbls)
OIL PRODUCTION (bbls)
1000000
100000
10000
1000
100
10
1
YEAR

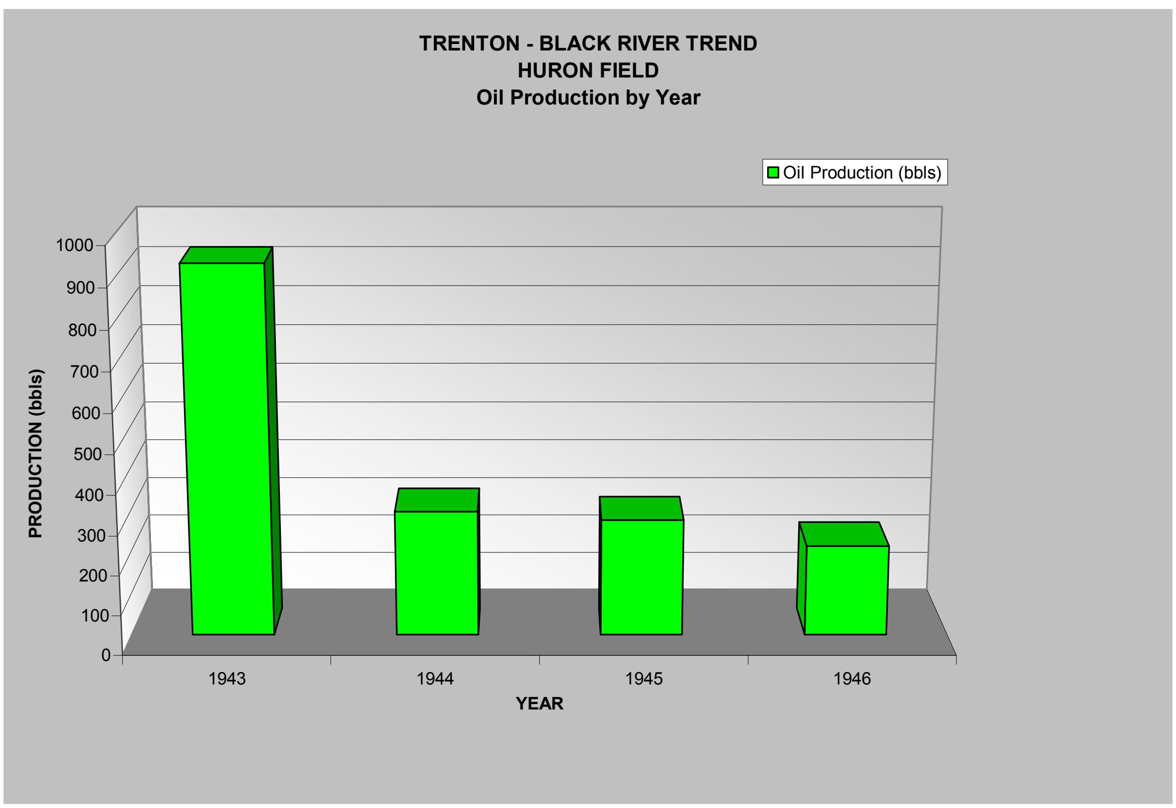

TRENTON - BLACK RIVER TREND
FREEDOM FIELD
Oil - Water Production by Year
Water Production (bbls)
Oil Production (bbls)
PRODUCTION
Oil - Water (bbls)
6000
5000
4000
3000
2000
1000
0
1954
1955
1956
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
YEAR

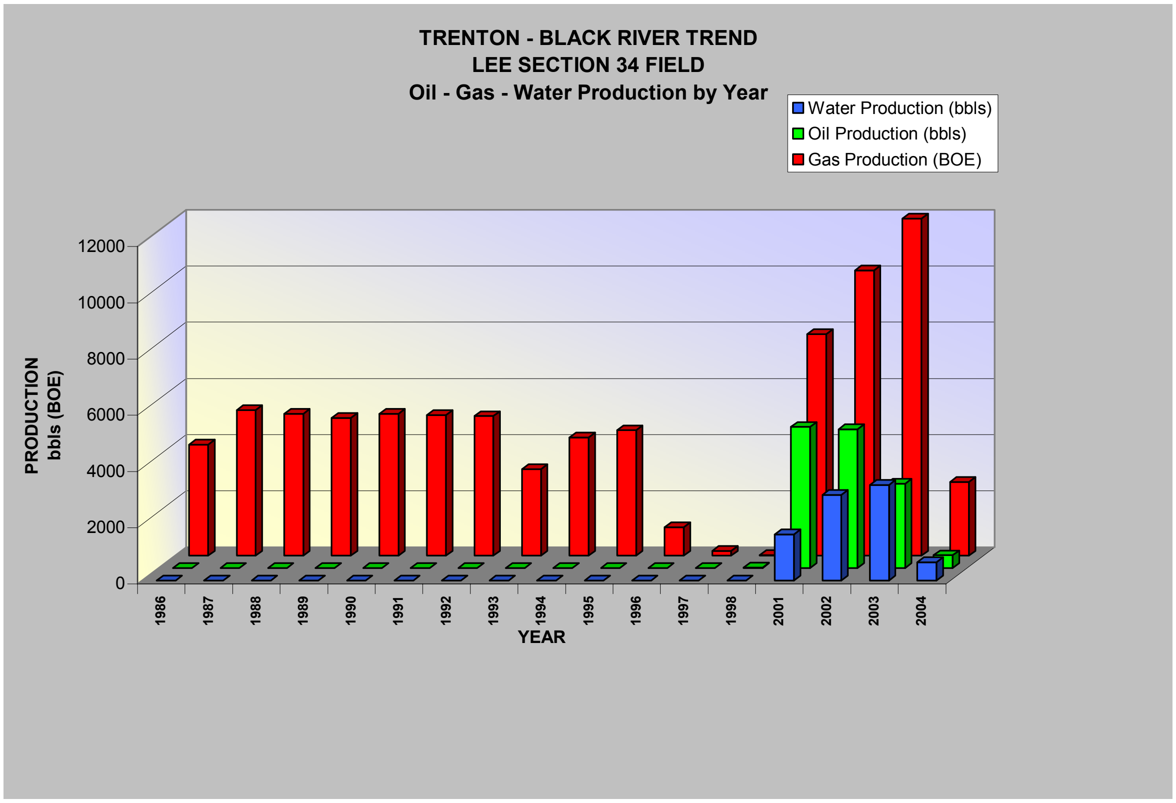

TRENTON BLACK RIVER TREND
GREEN OAK FIELD
Oil - Gas Production by Year
Oil Production (bbls)
Gas Production (BOE)
PRODUCTION
bbls/BOE
8000
7000
6000
5000
4000
3000
2000
1000
0
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1990
1994
1995
YEAR

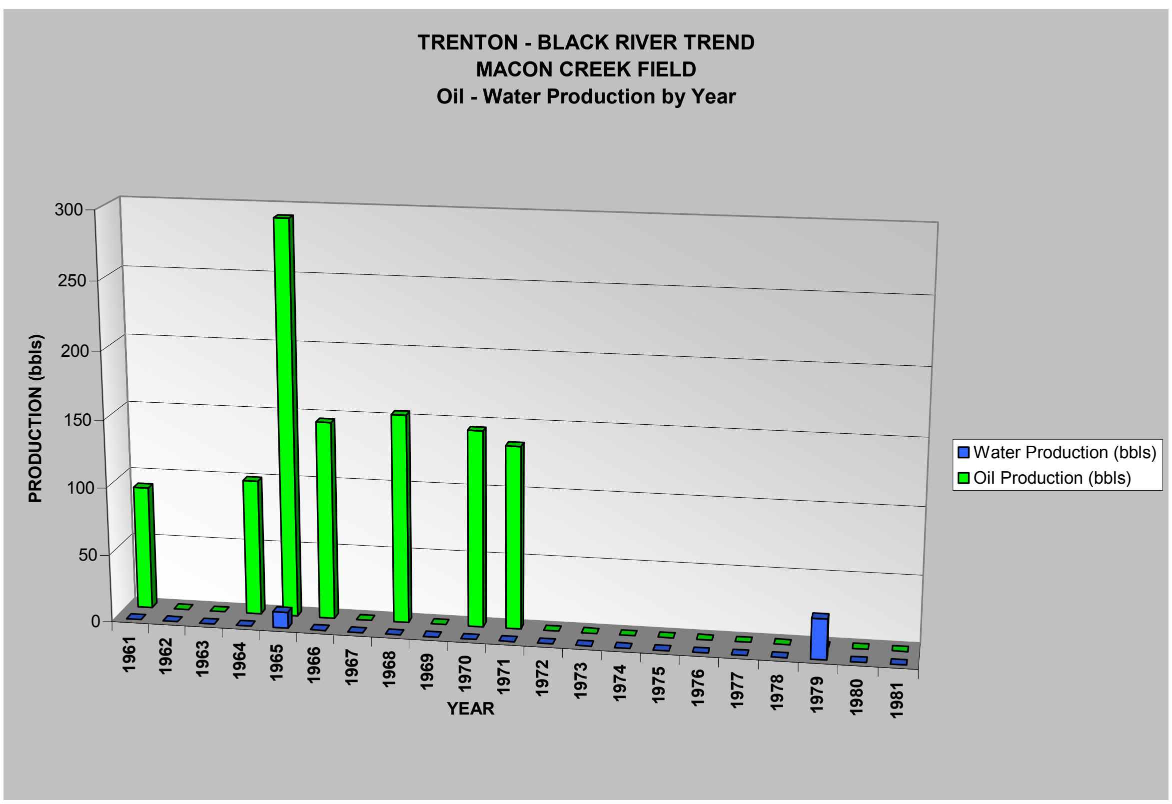

TRENTON - BLACK RIVER TREND
HANOVER FIELD
Oil - Gas - Water Production by Year
Water Production (bbls)
Gas Production (BOE)
Oil Production (bbls)
PRODUCTION
(bbls/BOE)
250000
200000
150000
100000
50000
0
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
YEAR

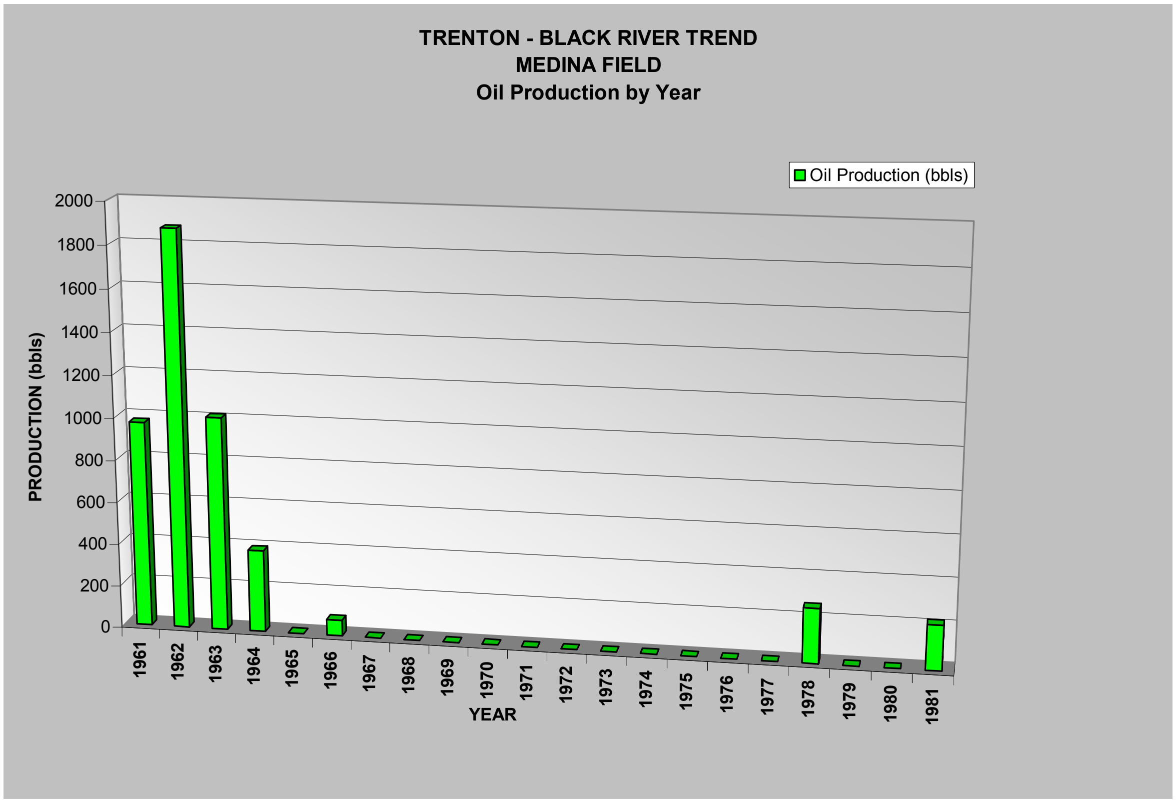

TRENTON - BLACK RIVER TREND
HANOVER SECTION 13 FIELD
Oil Production by Year (1997)
PRODUCTIOIN (bbls)
3000
2500
2000
1500
1000
500
0
1997
YEAR
Oil Production (bbls)

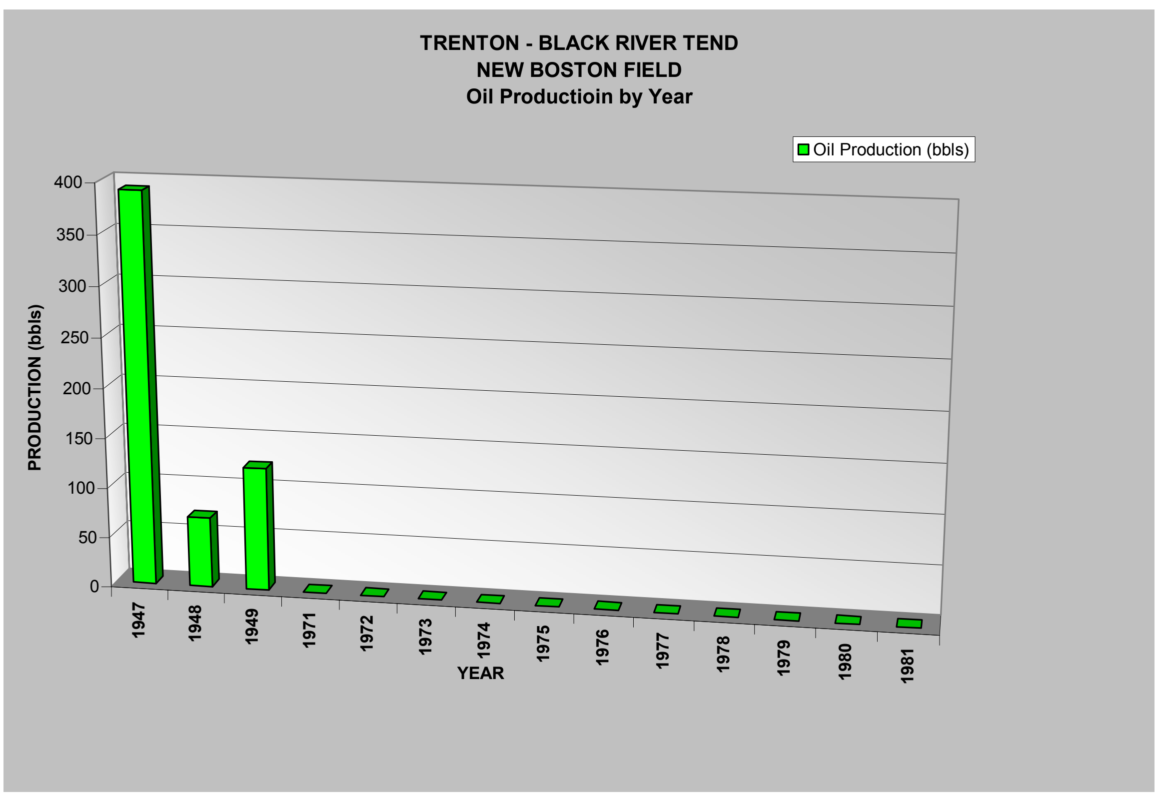

TRENTON - BLACK RIVER TREND
HENRIETTA FIELD
Oil Production by Year
Oil Production (bbls)
PRODUCTION (bbls)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
1979
1980
1981
YEAR

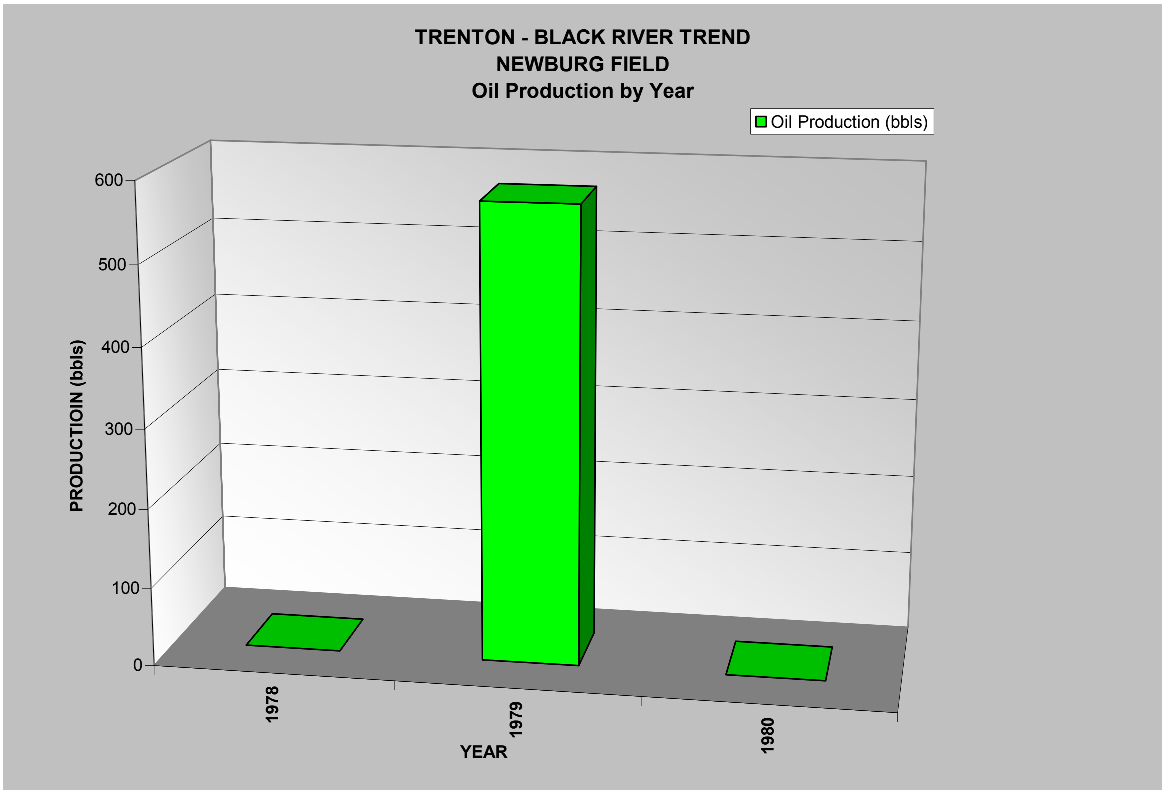

TRENTON - BLACK RIVER TREND
HURON FIELD
Oil Production by Year
Oil Production (bbls)
PRODUCTION (bbls)
0
100
200
300
400
500
600
700
800
900
1000
1943
1944
1945
1946
YEAR

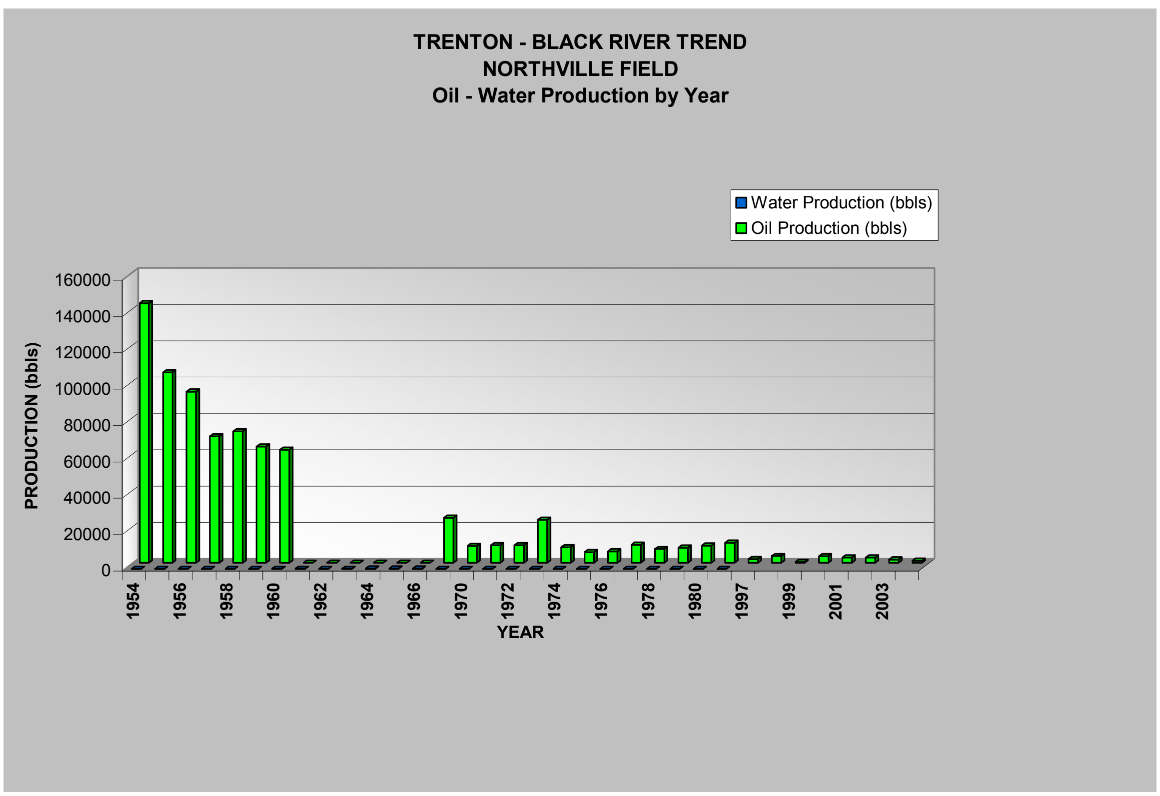

TRENTON - BLACK RIVER TREND
LEE SECTION 34 FIELD
Oil - Gas - Water Production by Year
Water Production (bbls)
Oil Production (bbls)
Gas Production (BOE)
PRODUCTION
bbls (BOE)
0
2000
4000
6000
8000
10000
12000
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
2001
2002
2003
2004
YEAR

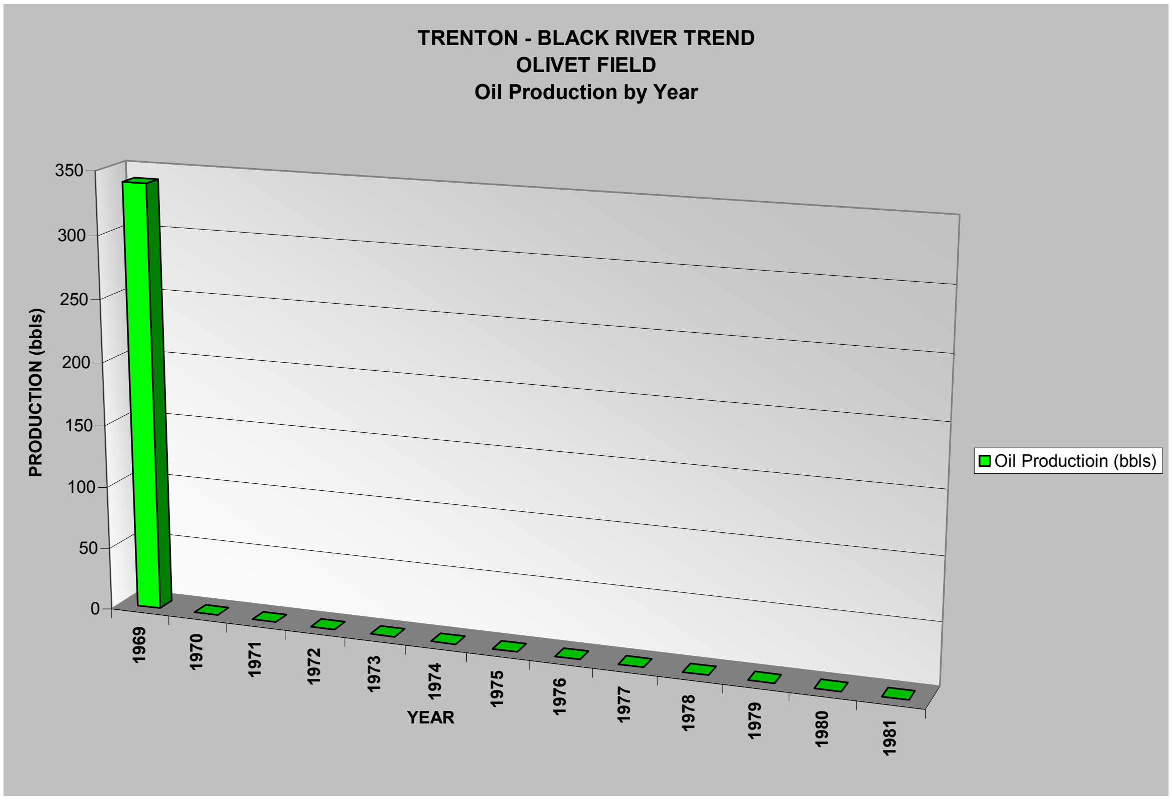

TRENTON - BLACK RIVER TREND
MACON CREEK FIELD
Oil - Water Production by Year
PRODUCTION (bbls)
0
50
100
150
200
250
300
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
YEAR
Water Production (bbls)
Oil Production (bbls)

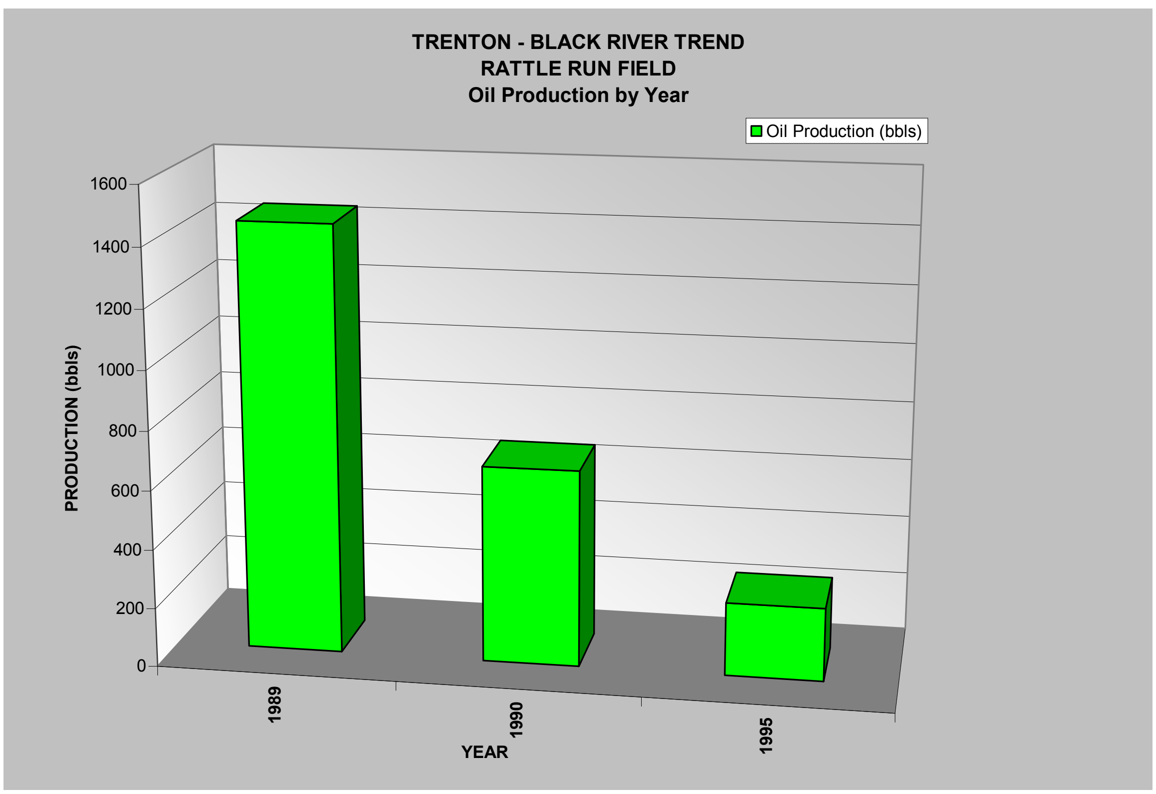

TRENTON - BLACK RIVER TREND
MEDINA FIELD
Oil Production by Year
Oil Production (bbls)
PRODUCTION (bbls)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
YEAR

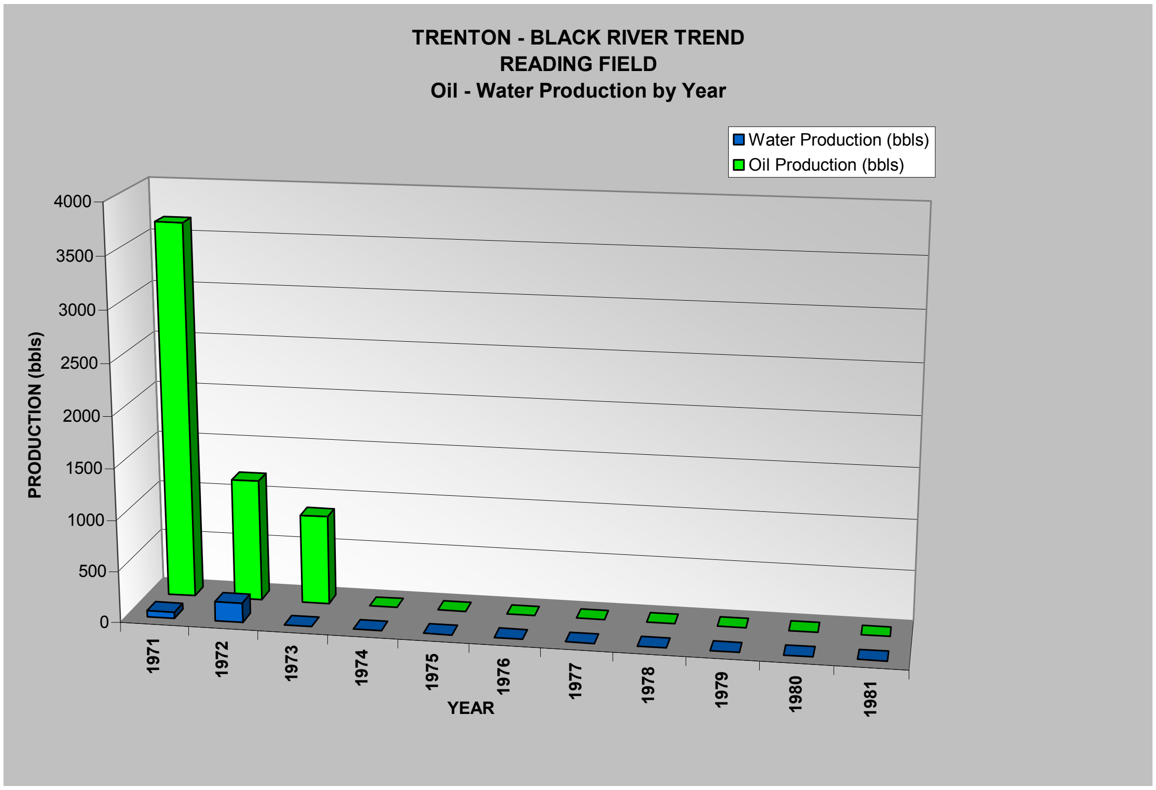

TRENTON - BLACK RIVER TEND
NEW BOSTON FIELD
Oil Productioin by Year
Oil Production (bbls)
PRODUCTION (bbls)
400
350
300
250
200
150
100
50
0
1947
1948
1949
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
YEAR

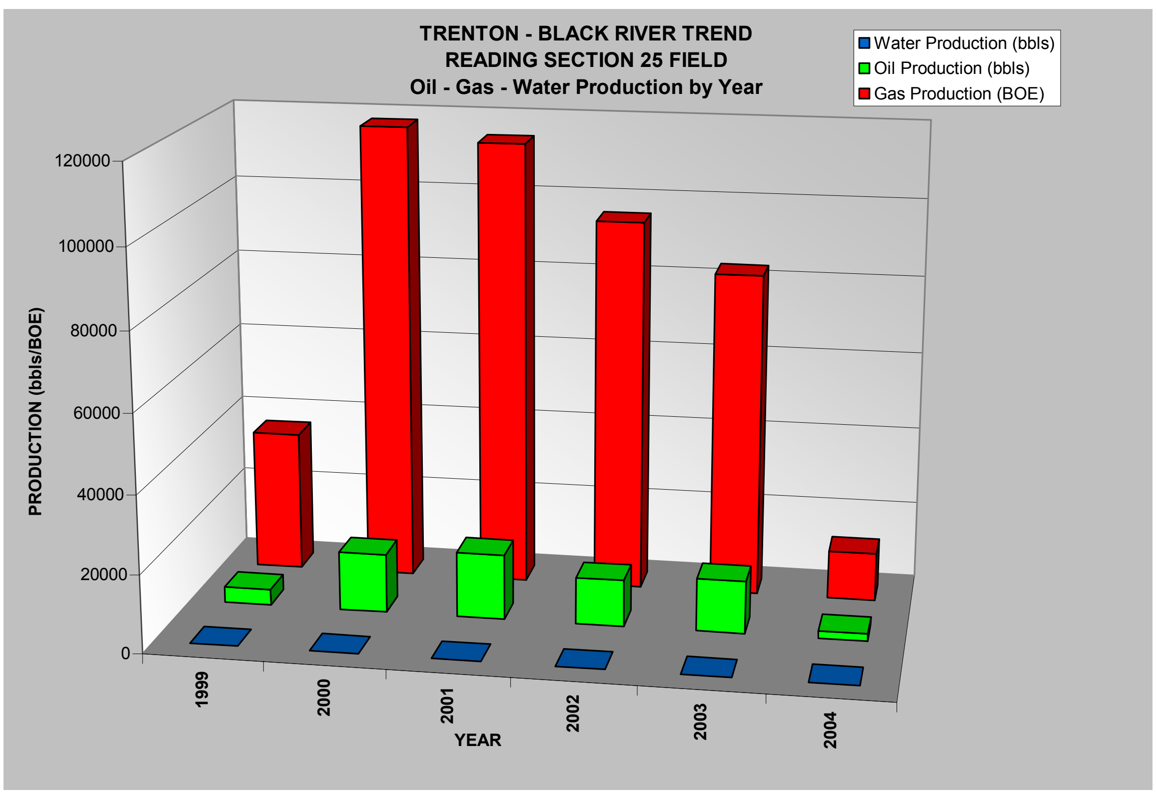

TRENTON - BLACK RIVER TREND
NEWBURG FIELD
Oil Production by Year
Oil Production (bbls)
PRODUCTIOIN (bbls)
600
500
400
300
200
100
0
1978
1979
1980
YEAR

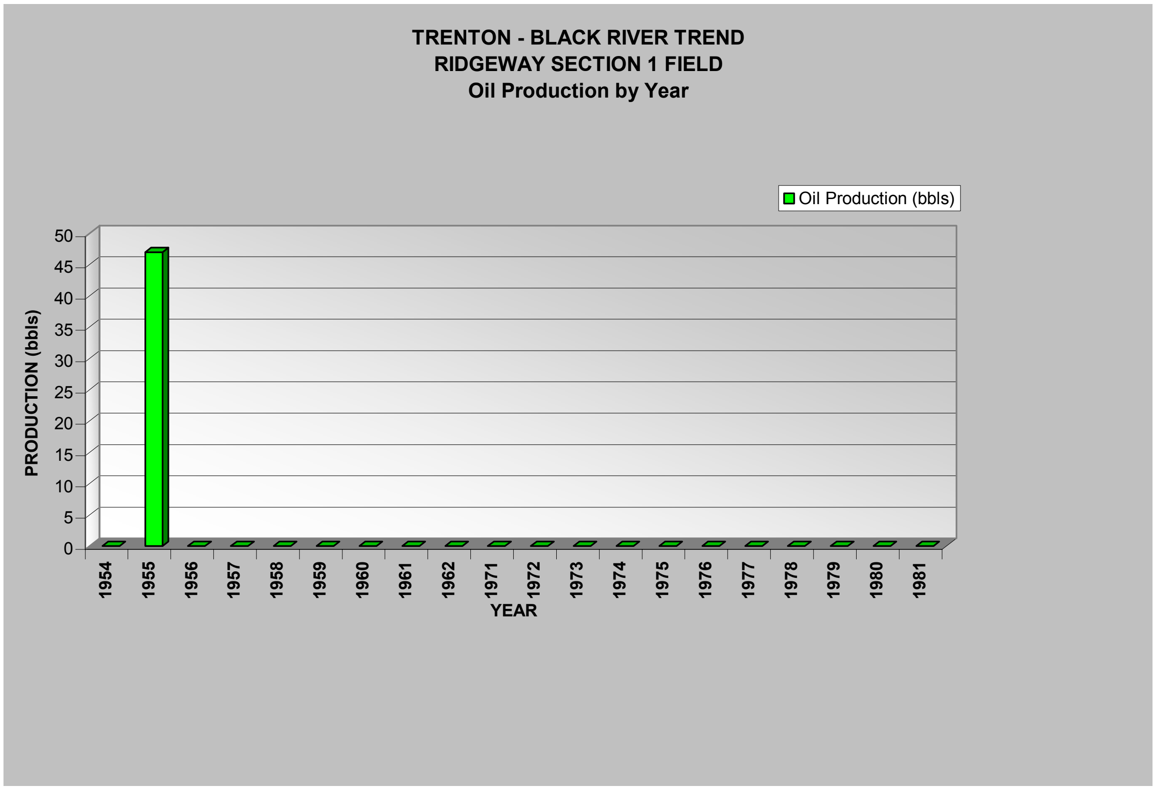

TRENTON - BLACK RIVER TREND
NORTHVILLE FIELD
Oil - Water Production by Year
Water Production (bbls)
Oil Production (bbls)
PRODUCTION (bbls)
160000
140000
120000
100000
80000
60000
40000
20000
0
1954
1956
1958
1960
1962
1964
1966
1970
1972
1974
1976
1978
1980
1997
1999
2001
2003
YEAR

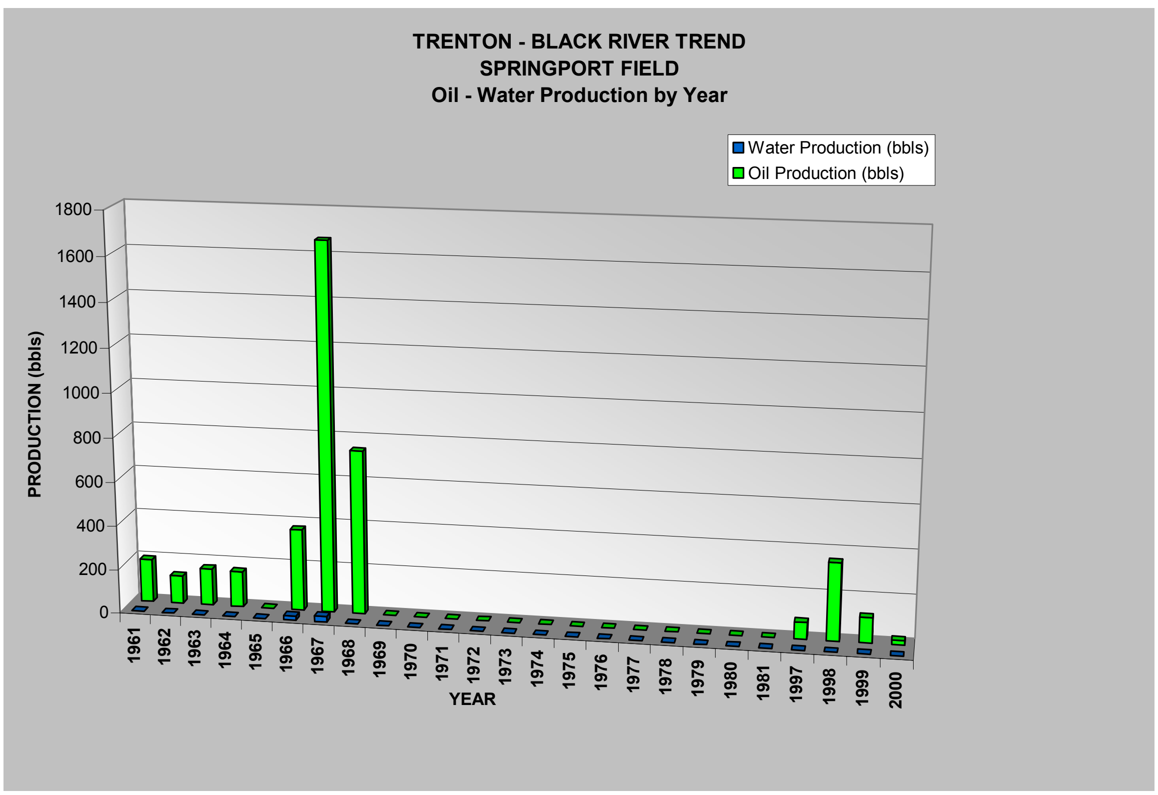

TRENTON - BLACK RIVER TREND
OLIVET FIELD
Oil Production by Year
PRODUCTION (bbls)
350
300
250
200
150
100
50
0
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
YEAR
Oil Productioin (bbls)

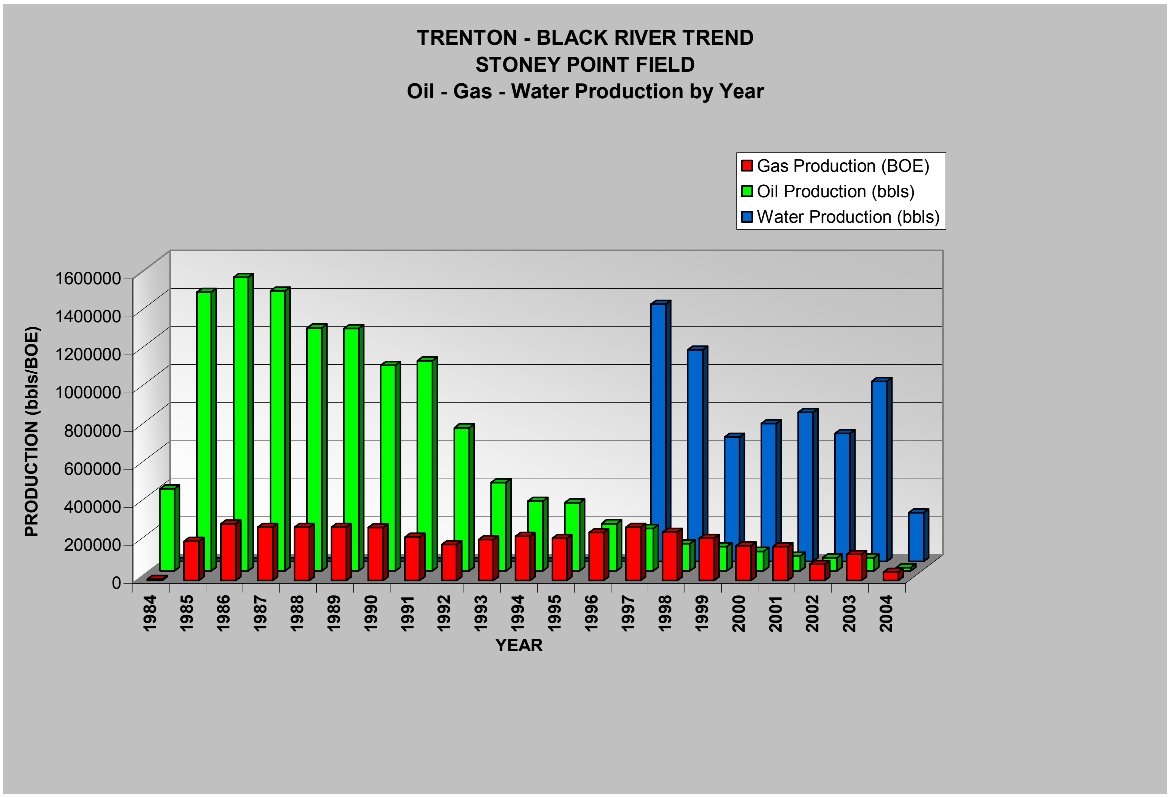

TRENTON - BLACK RIVER TREND
RATTLE RUN FIELD
Oil Production by Year
Oil Production (bbls)
PRODUCTION (bbls)
1600
1400
1200
1000
800
600
400
200
0
1989
1990
1995
YEAR

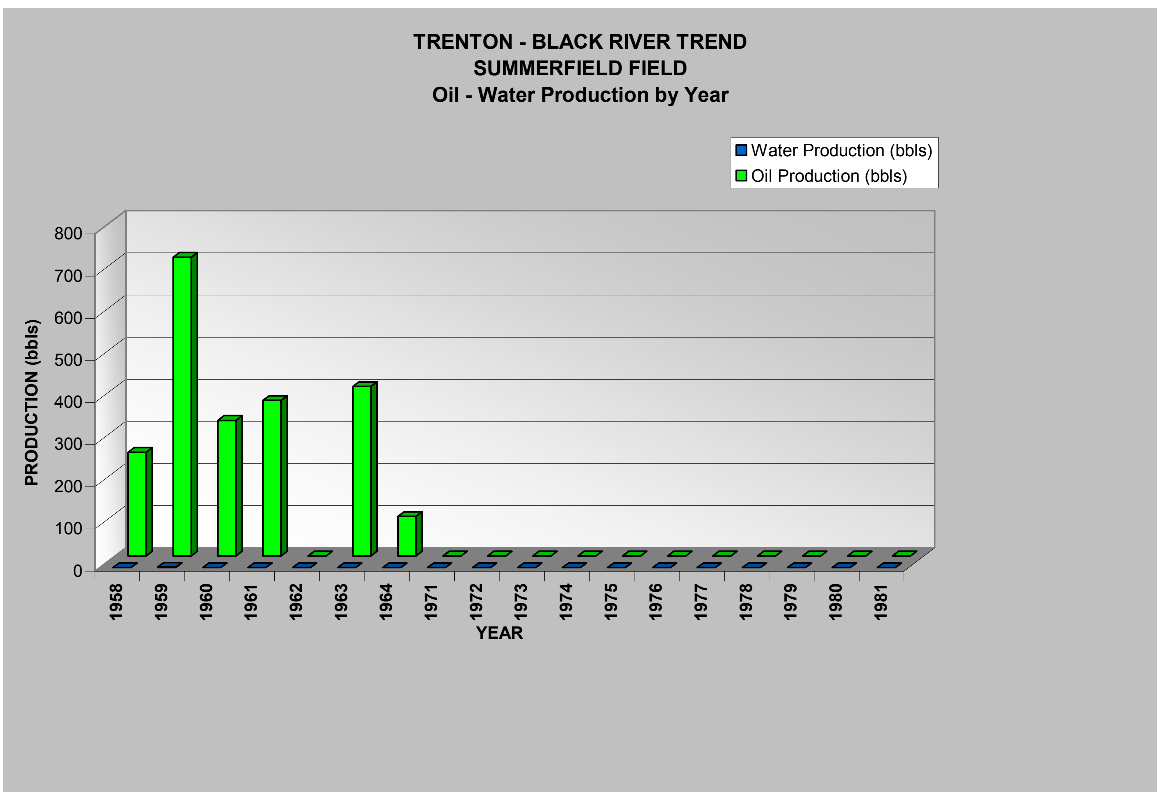

TRENTON - BLACK RIVER TREND
READING FIELD
Oil - Water Production by Year
Water Production (bbls)
Oil Production (bbls)
PRODUCTION (bbls)
4000
3500
3000
2500
2000
1500
1000
500
0
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
YEAR

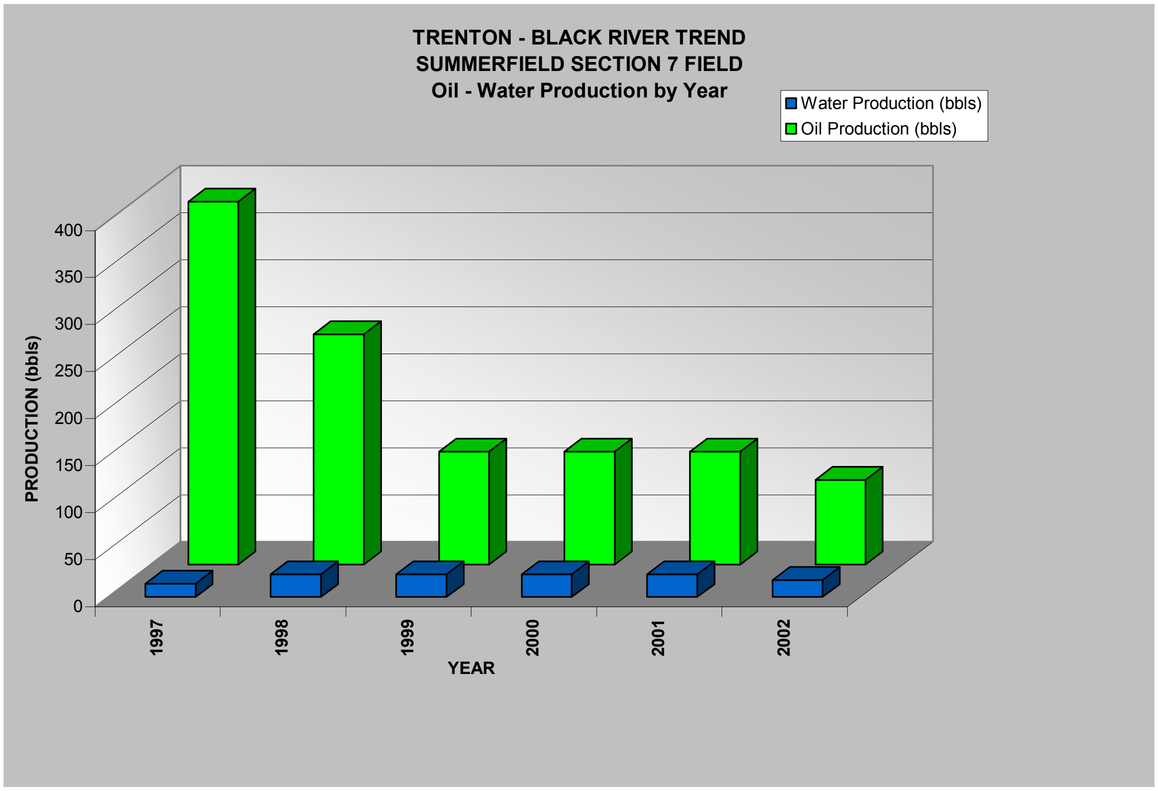

TRENTON - BLACK RIVER TREND
READING SECTION 25 FIELD
Oil - Gas - Water Production by Year
Water Production (bbls)
Oil Production (bbls)
Gas Production (BOE)
PRODUCTION (bbls/BOE)
120000
100000
80000
60000
40000
20000
0
1999
2000
2001
2002
2003
2004
YEAR

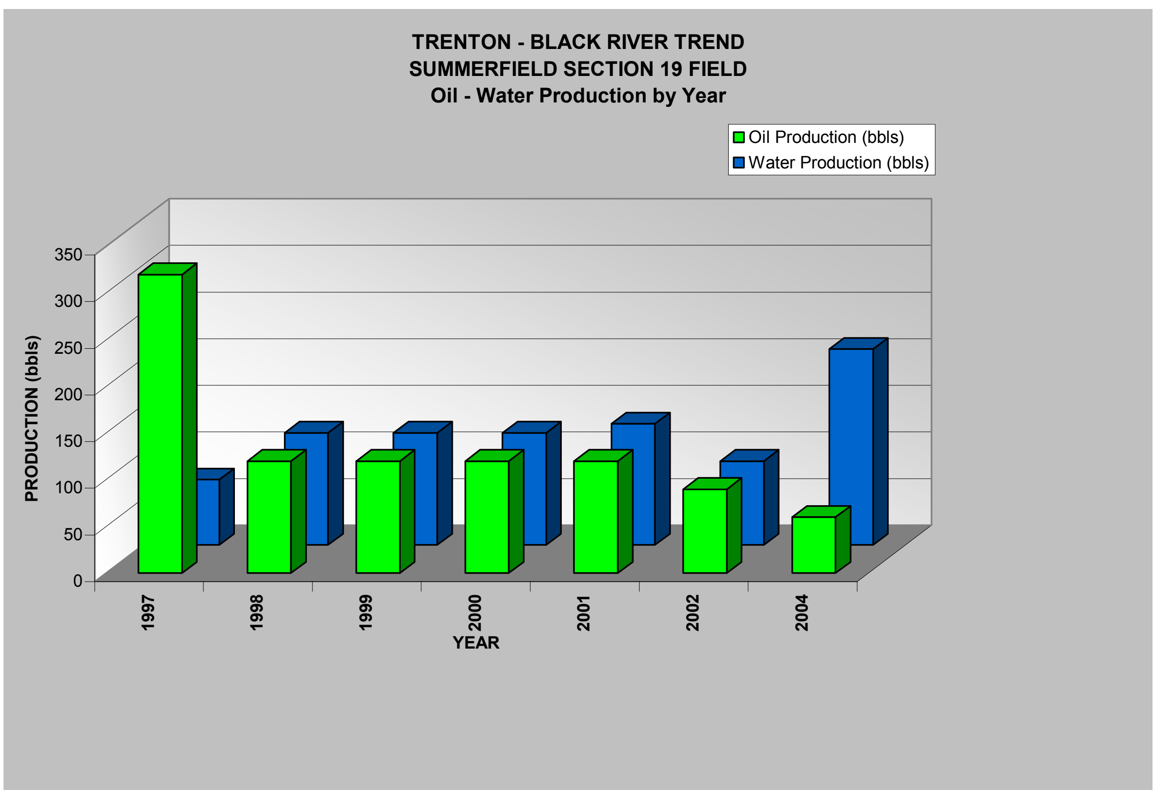

TRENTON - BLACK RIVER TREND
RIDGEWAY SECTION 1 FIELD
Oil Production by Year
Oil Production (bbls)
PRODUCTION (bbls)
0
5
10
15
20
25
30
35
40
45
50
1954
1955
1956
1957
1958
1959
1960
1961
1962
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
YEAR

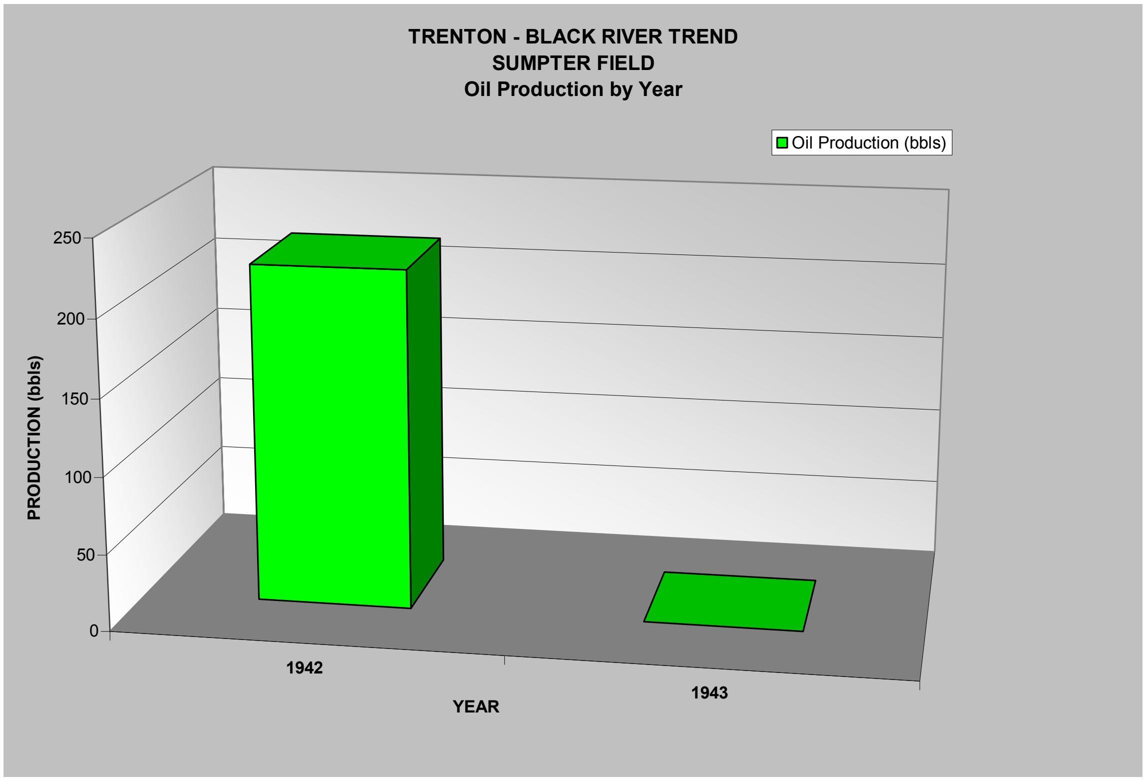

TRENTON - BLACK RIVER TREND
SPRINGPORT FIELD
Oil - Water Production by Year
Water Production (bbls)
Oil Production (bbls)
PRODUCTION (bbls)
0
200
400
600
800
1000
1200
1400
1600
1800
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1997
1998
1999
2000
YEAR

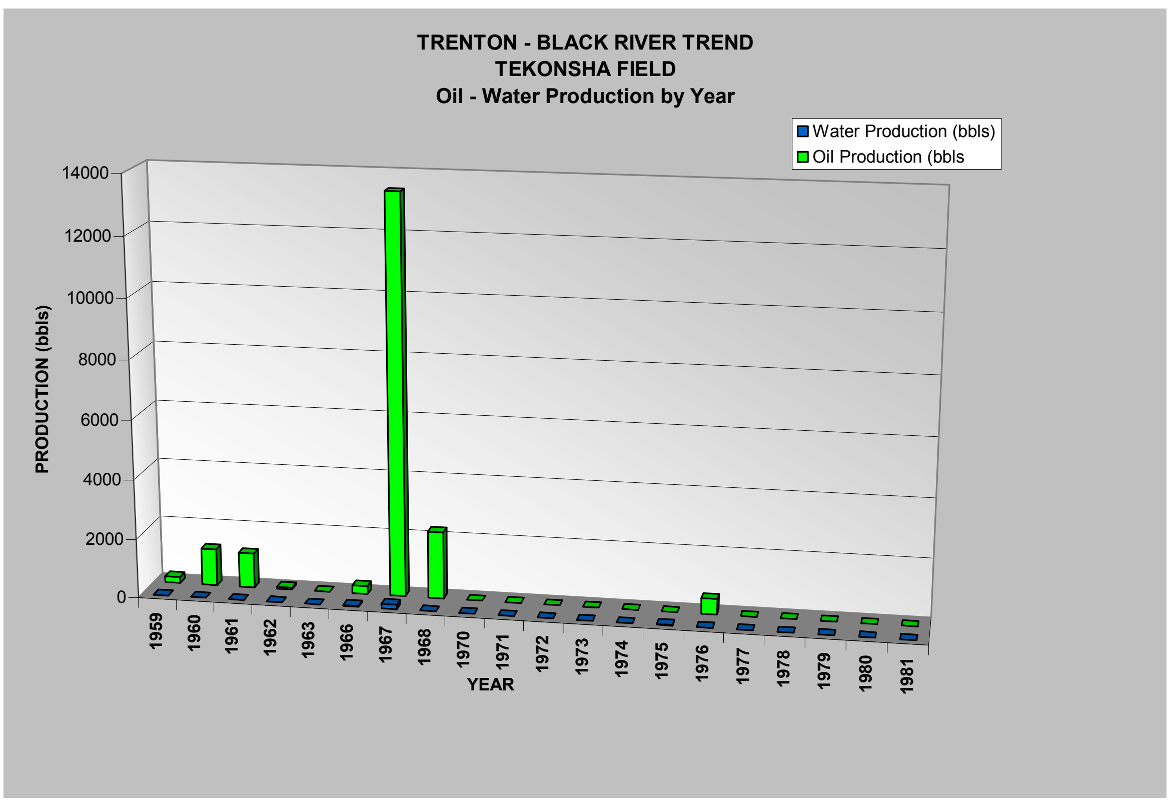

TRENTON - BLACK RIVER TREND
STONEY POINT FIELD
Oil - Gas - Water Production by Year
Gas Production (BOE)
Oil Production (bbls)
Water Production (bbls)
PRODUCTION (bbls/BOE)
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
YEAR

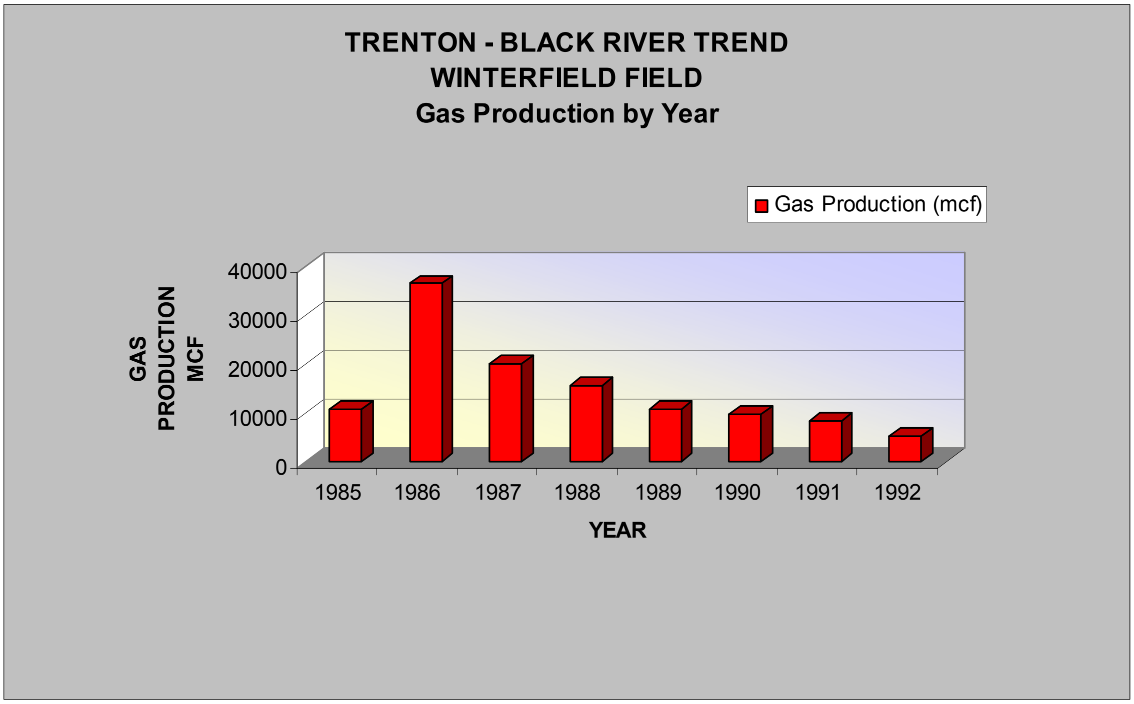

TRENTON - BLACK RIVER TREND
SUMMERFIELD FIELD
Oil - Water Production by Year
Water Production (bbls)
Oil Production (bbls)
PRODUCTION (bbls)
800
700
600
500
400
300
200
100
0
1958
1959
1960
1961
1962
1963
1964
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
YEAR


TRENTON - BLACK RIVER TREND
SUMMERFIELD SECTION 7 FIELD
Oil - Water Production by Year
Water Production (bbls)
Oil Production (bbls)
PRODUCTION (bbls)
0
50
100
150
200
250
300
350
400
1997
1998
1999
2000
2001
2002
YEAR

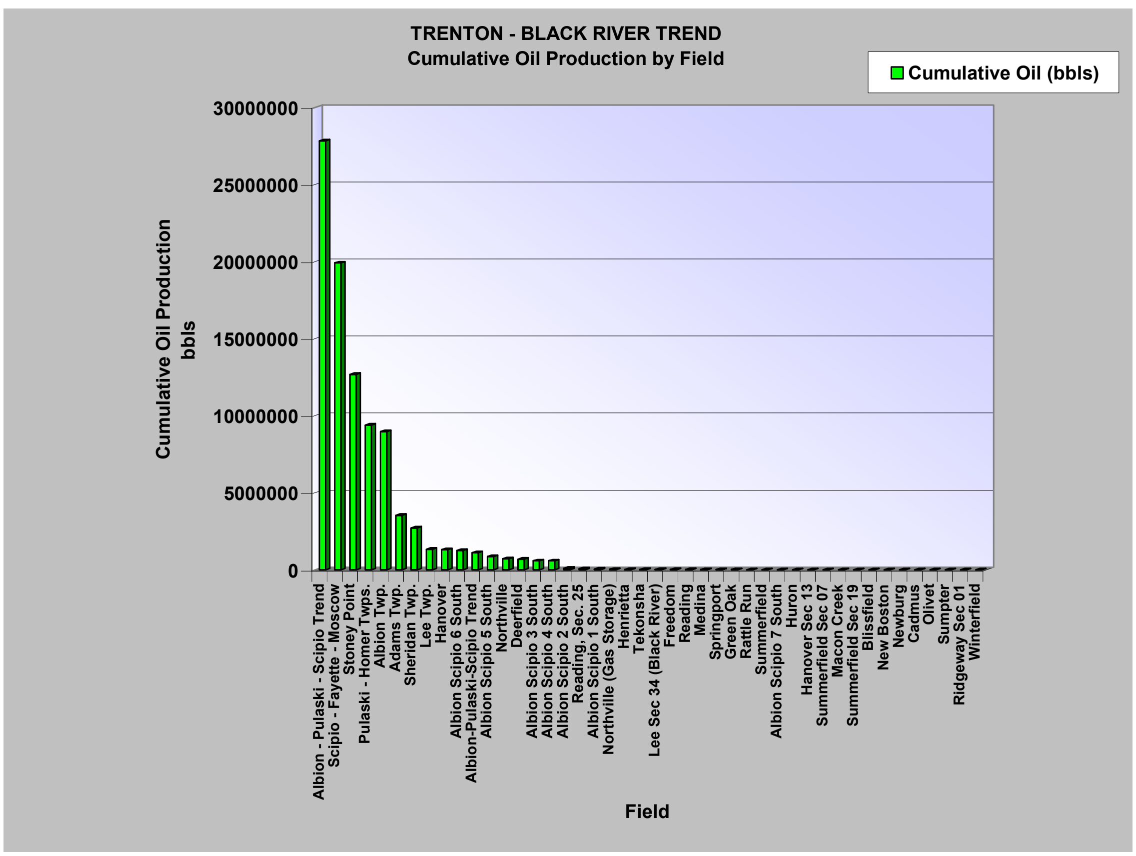

TRENTON - BLACK RIVER TREND
SUMMERFIELD SECTION 19 FIELD
Oil - Water Production by Year
Oil Production (bbls)
Water Production (bbls)
PRODUCTION (bbls)
0
50
100
150
200
250
300
350
1997
1998
1999
2000
2001
2002
2004
YEAR


TRENTON - BLACK RIVER TREND
SUMPTER FIELD
Oil Production by Year
Oil Production (bbls)
PRODUCTION (bbls)
0
50
100
150
200
250
1942
1943
YEAR

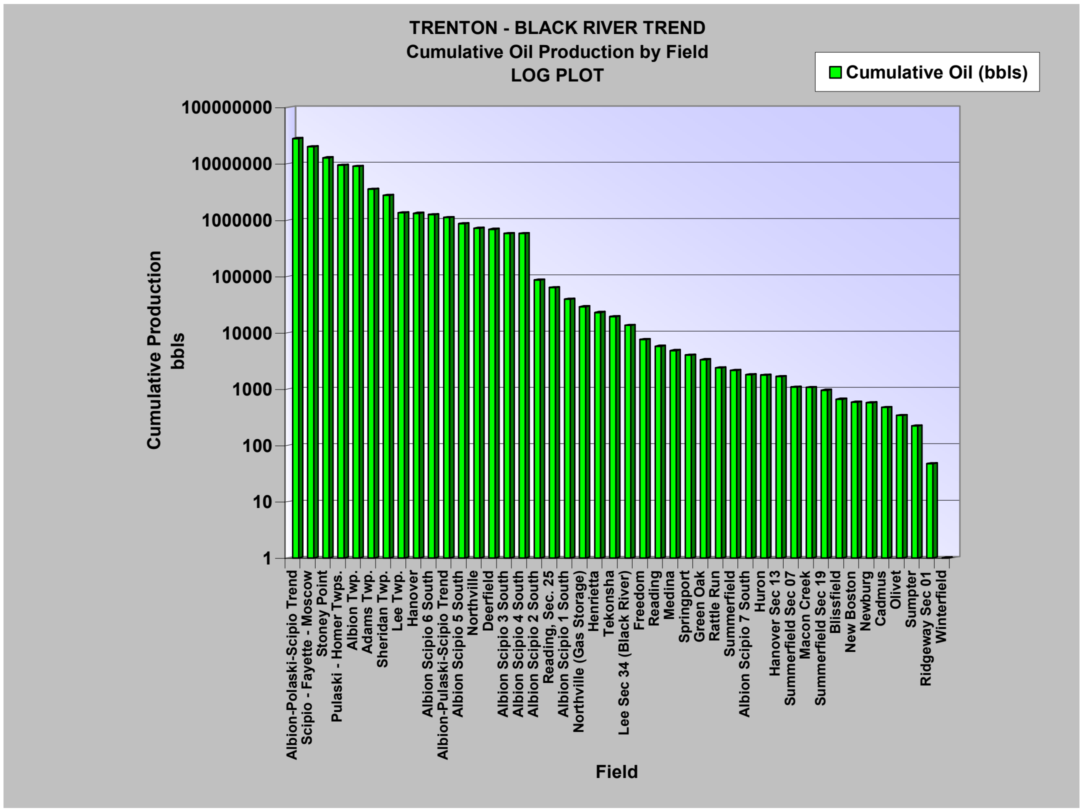

TRENTON - BLACK RIVER TREND
TEKONSHA FIELD
Oil - Water Production by Year
Water Production (bbls)
Oil Production (bbls
PRODUCTION (bbls)
0
2000
4000
6000
8000
10000
12000
14000
1959
1960
1961
1962
1963
1966
1967
1968
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
YEAR

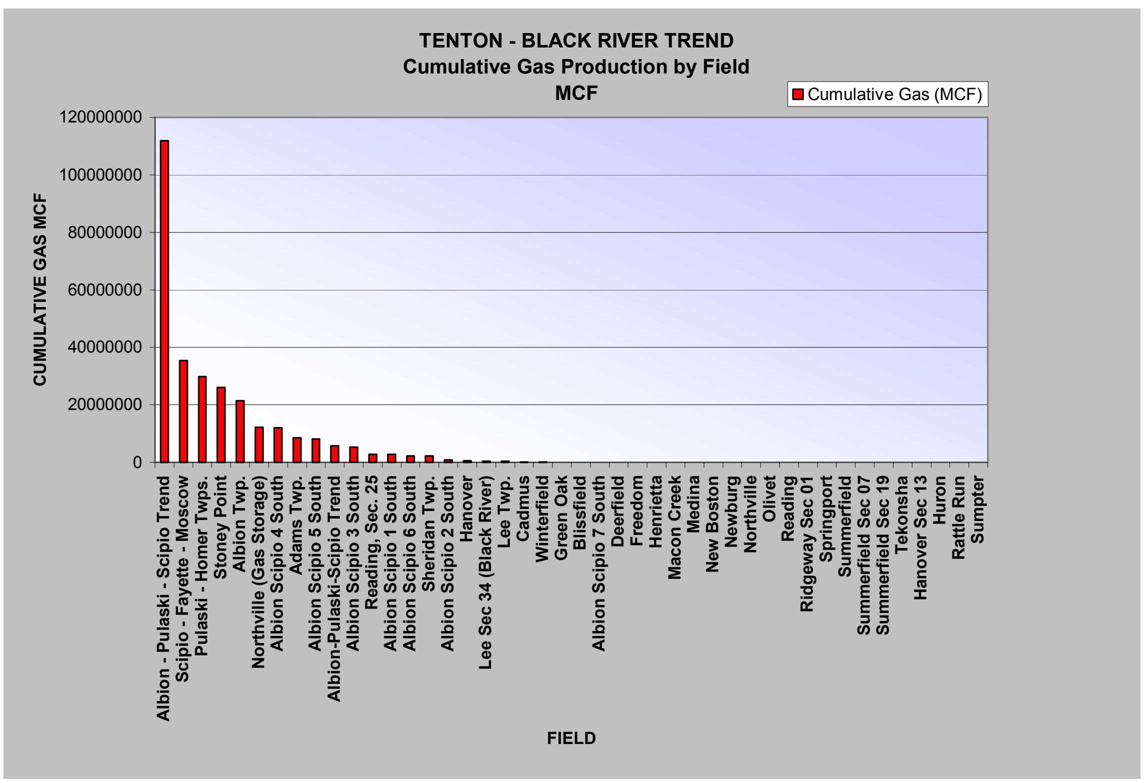


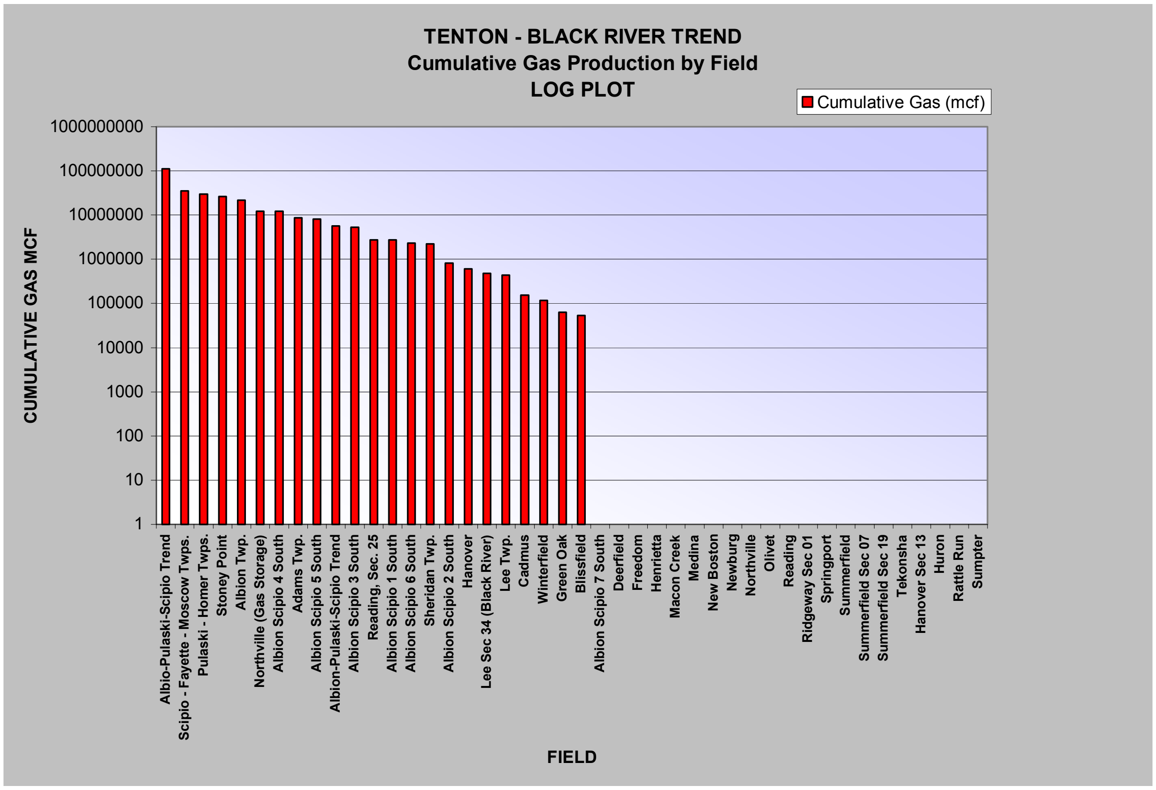
TRENTON - BLACK RIVER TREND
WINTERFIELD FIELD
Gas Production by Year
Gas Production (mcf)
GAS PRODUCTION MCF
40000
30000
20000
10000
0
1985
1986
1987
1988
1989
1990
1991
1992
YEAR

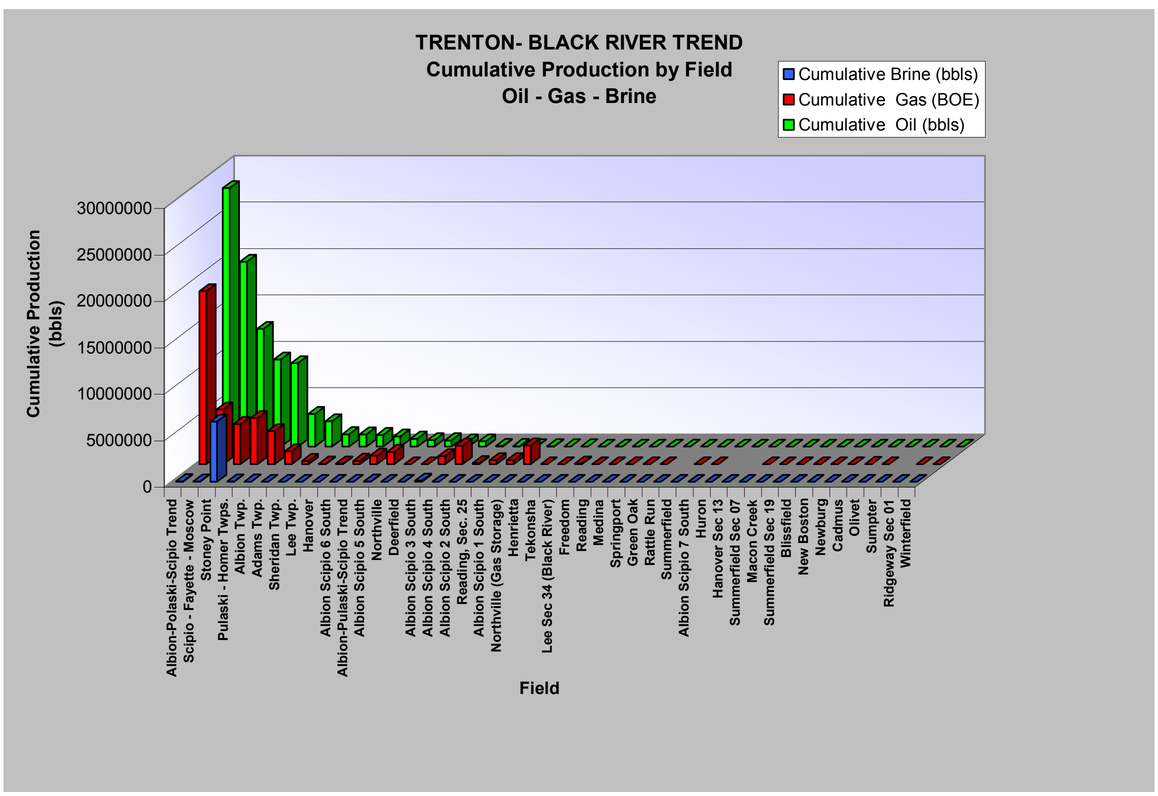


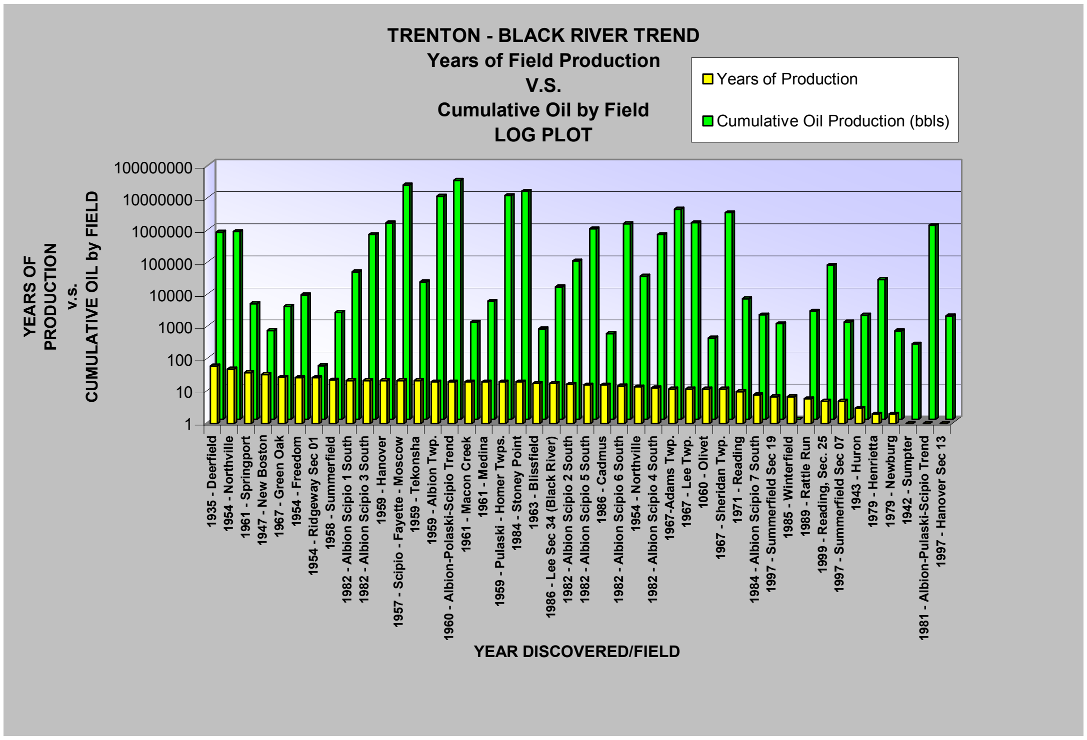
TRENTON - BLACK RIVER TREND
Cumulative Oil Production by Field
Cumulative Oil (bbls)
Cumulative Oil Production bbls
30000000
25000000
20000000
15000000
10000000
5000000
0
Albion - Pulaski - Scipio Trend
Scipio - Fayette - Moscow
Stoney Point
Pulaski - Homer Twps.
Albion Twp.
Adams Twp.
Sheridan Twp.
Lee Twp.
Hanover
Albion Scipio 6 South
Albion-Pulaski-Scipio Trend
Albion Scipio 5 South
Northville
Deerfield
Albion Scipio 3 South
Albion Scipio 4 South
Albion Scipio 2 South
Reading, Sec. 25
Albion Scipio 1 South
Northville (Gas Storage)
Henrietta
Tekonsha
Lee Sec 34 (Black River)
Freedom
Reading
Medina
Springport
Green Oak
Rattle Run
Summerfield
Albion Scipio 7 South
Huron
Hanover Sec 13
Summerfield Sec 07
Macon Creek
Summerfield Sec 19
Blissfield
New Boston
Newburg
Cadmus
Olivet
Sumpter
Ridgeway Sec 01
Winterfield
Field

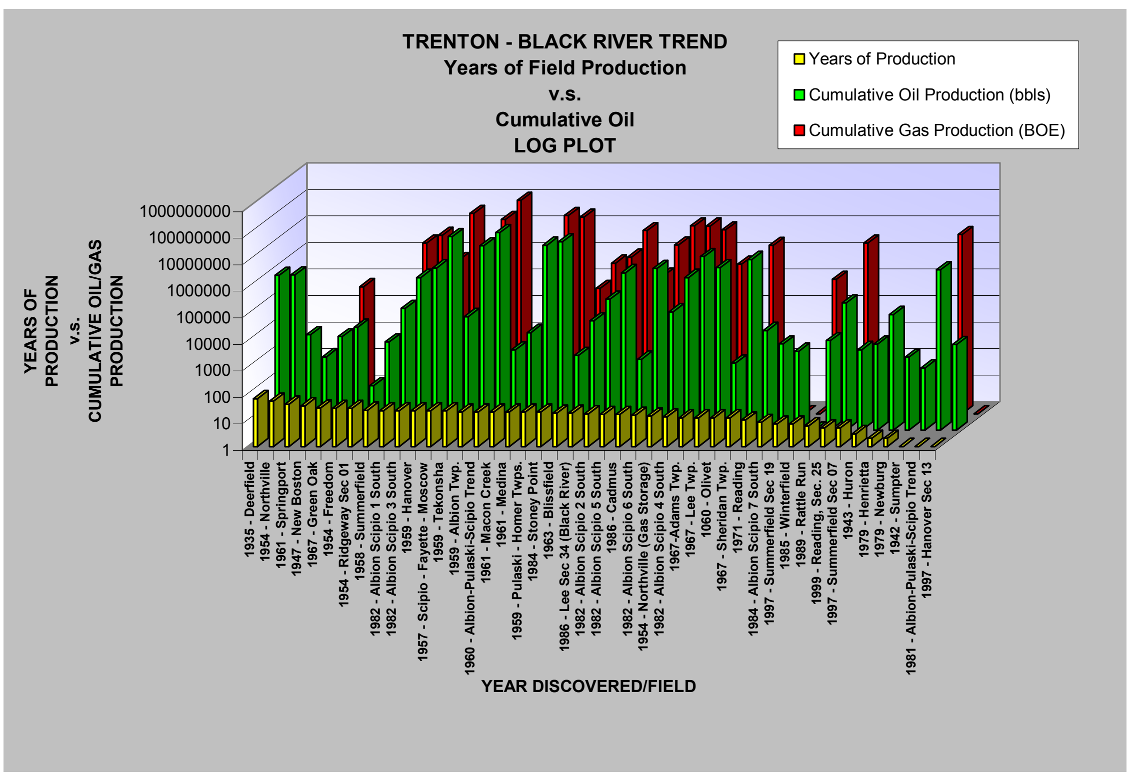

TRENTON - BLACK RIVER TREND
Cumulative Oil Production by Field
LOG PLOT
Cumulative Oil (bbls)
Cumulative Production bbls
100000000
10000000
1000000
100000
10000
1000
100
10
1
Albion-Pulaski-Scipio Trend
Scipio - Fayette - Moscow
Stoney Point
Pulaski - Homer Twps.
Albion Twp.
Adams Twp.
Sheridan Twp.
Lee Twp.
Hanover
Albion Scipio 6 South
Albion-Pulaski-Scipio Trend
Albion Scipio 5 South
Northville
Deerfield
Albion Scipio 3 South
Albion Scipio 4 South
Albion Scipio 2 South
Reading, Sec. 25
Albion Scipio 1 South
Northville (Gas Storage)
Henrietta
Tekonsha
Lee Sec 34 (Black River)
Freedom
Reading
Medina
Springport
Green Oak
Rattle Run
Summerfield
Albion Scipio 7 South
Huron
Hanover Sec 13
Summerfield Sec 07
Macon Creek
Summerfield Sec 19
Blissfield
New Boston
Newburg
Cadmus
Olivet
Sumpter
Ridgeway Sec 01
Winterfield
Field


TENTON - BLACK RIVER TREND
Cumulative Gas Production by Field
MCF
Cumulative Gas (MCF)
CUMULATIVE GAS MCF
120000000
100000000
80000000
60000000
40000000
20000000
0
Albion - Pulaski - Scipio Trend
Scipio - Fayette - Moscow
Pulaski - Homer Twps.
Stoney Point
Albion Twp.
Northville (Gas Storage)
Albion Scipio 4 South
Adams Twp.
Albion Scipio 5 South
Albion-Pulaski-Scipio Trend
Albion Scipio 3 South
Reading, Sec. 25
Albion Scipio 1 South
Albion Scipio 6 South
Sheridan Twp.
Albion Scipio 2 South
Hanover
Lee Sec 34 (Black River)
Lee Twp.
Cadmus
Winterfield
Green Oak
Blissfield
Albion Scipio 7 South
Deerfield
Freedom
Henrietta
Macon Creek
Medina
New Boston
Newburg
Northville
Olivet
Reading
Ridgeway Sec 01
Springport
Summerfield
Summerfield Sec 07
Summerfield Sec 19
Tekonsha
Hanover Sec 13
Huron
Rattle Run
Sumpter
FIELD

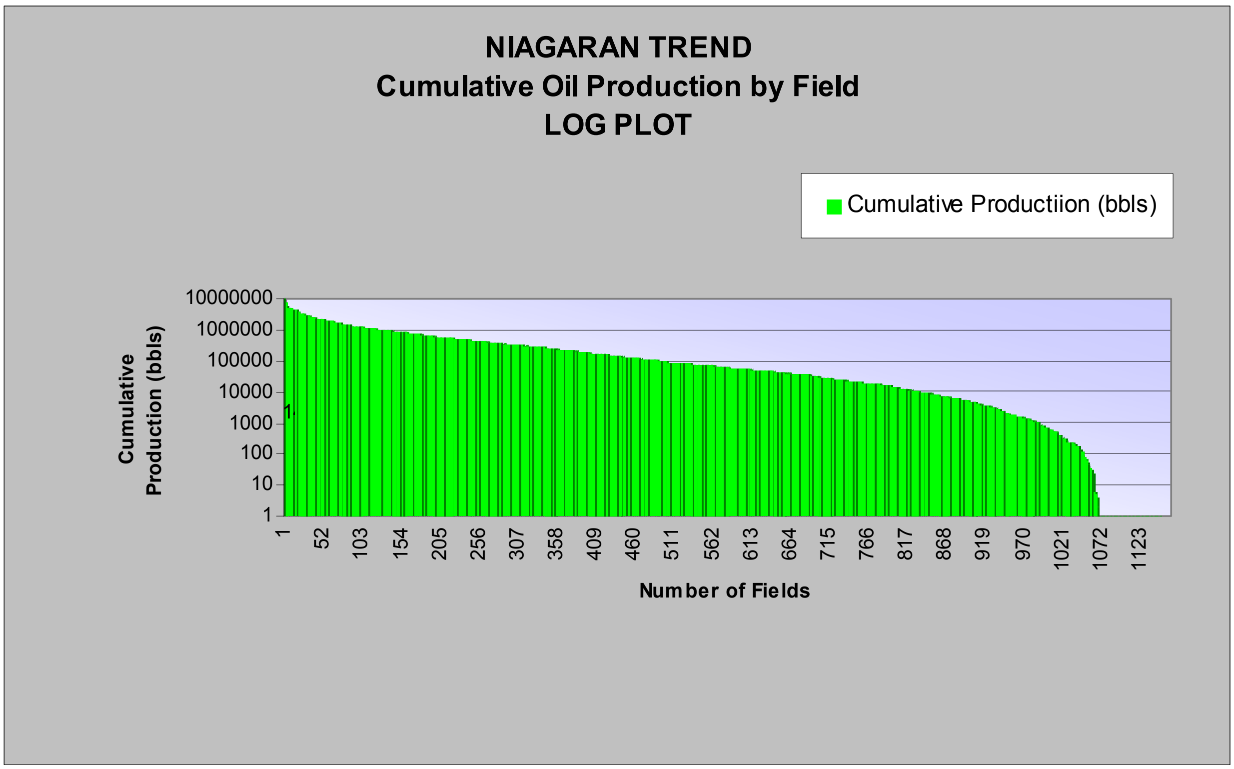

TENTON - BLACK RIVER TREND
Cumulative Gas Production by Field
LOG PLOT
Cumulative Gas (mcf)
CUMULATIVE GAS MCF
1000000000
100000000
10000000
1000000
100000
10000
1000
100
10
1
Albio-Pulaski-Scipio Trend
Scipio - Fayette - Moscow Twps.
Pulaski - Homer Twps.
Stoney Point
Albion Twp.
Northville (Gas Storage)
Albion Scipio 4 South
Adams Twp.
Albion Scipio 5 South
Albion-Pulaski-Scipio Trend
Albion Scipio 3 South
Reading, Sec. 25
Albion Scipio 1 South
Albion Scipio 6 South
Sheridan Twp.
Albion Scipio 2 South
Hanover
Lee Sec 34 (Black River)
Lee Twp.
Cadmus
Winterfield
Green Oak
Blissfield
Albion Scipio 7 South
Deerfield
Freedom
Henrietta
Macon Creek
Medina
New Boston
Newburg
Northville
Olivet
Reading
Ridgeway Sec 01
Springport
Summerfield
Summerfield Sec 07
Summerfield Sec 19
Tekonsha
Hanover Sec 13
Huron
Rattle Run
Sumpter
FIELD

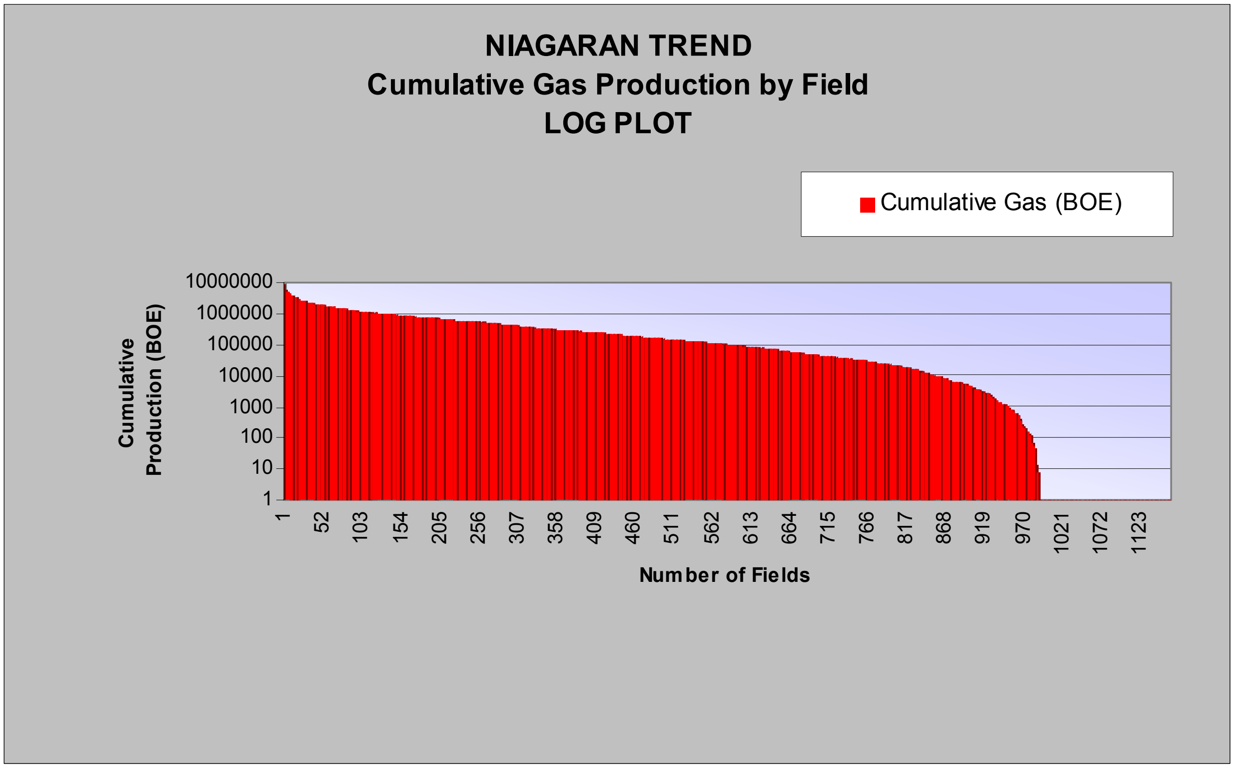

TRENTON- BLACK RIVER TREND
Cumulative Production by Field
Oil - Gas - Brine
Cumulative Brine (bbls)
Cumulative Gas (BOE)
Cumulative Oil (bbls)
Cumulative Production
(bbls)
30000000
25000000
20000000
15000000
10000000
5000000
0
Albion-Polaski-Scipio Trend
Scipio - Fayette - Moscow
Stoney Point
Pulaski - Homer Twps.
Albion Twp.
Adams Twp.
Sheridan Twp.
Lee Twp.
Hanover
Albion Scipio 6 South
Albion-Pulaski-Scipio Trend
Albion Scipio 5 South
Northville
Deerfield
Albion Scipio 3 South
Albion Scipio 4 South
Albion Scipio 2 South
Reading, Sec. 25
Albion Scipio 1 South
Northville (Gas Storage)
Henrietta
Tekonsha
Lee Sec 34 (Black River)
Freedom
Reading
Medina
Springport
Green Oak
Rattle Run
Summerfield
Albion Scipio 7 South
Huron
Hanover Sec 13
Summerfield Sec 07
Macon Creek
Summerfield Sec 19
Blissfield
New Boston
Newburg
Cadmus
Olivet
Sumpter
Ridgeway Sec 01
Winterfield
Field

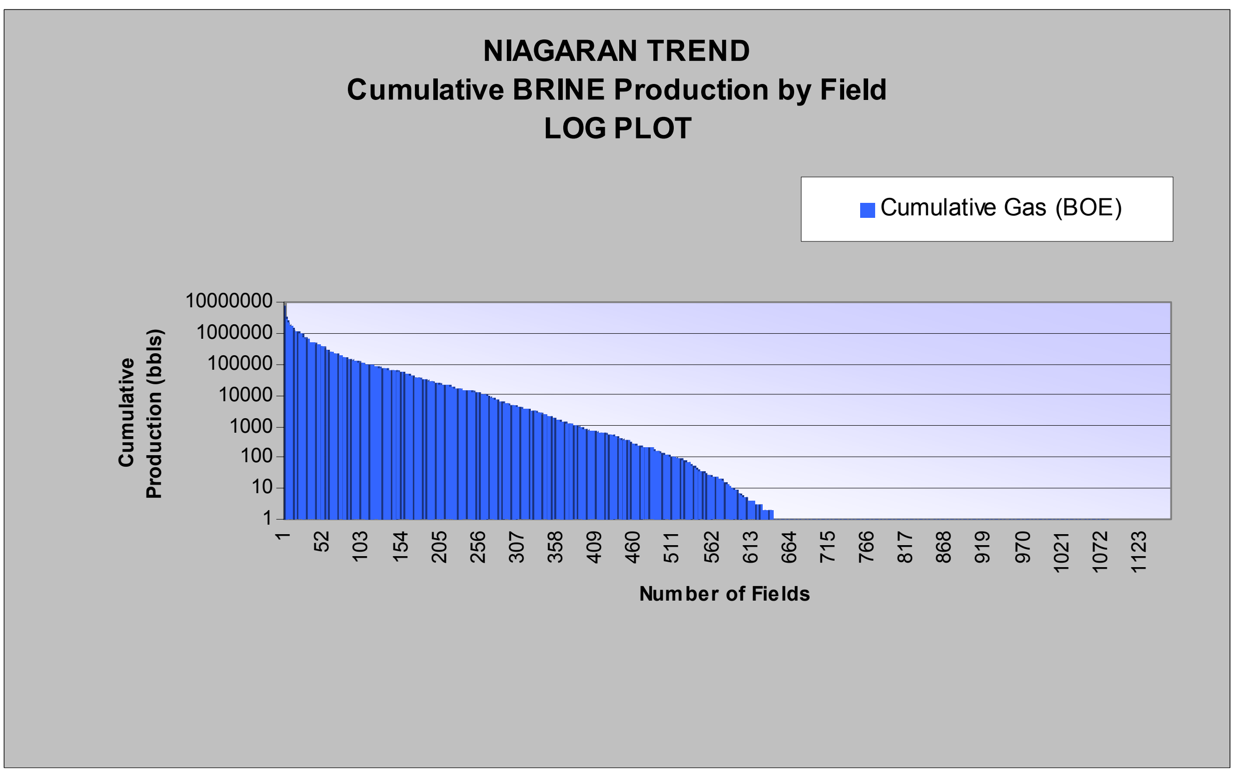

TRENTON - BLACK RIVER TREND
Years of Field Production
V.S.
Cumulative Oil by Field
LOG PLOT
Years of Production
Cumulative Oil Production (bbls)
YEARS OF PRODUCTION v.s. CUMULATIVE OIL by FIELD
100000000
10000000
1000000
100000
10000
1000
100
10
1
1935 - Deerfield
1954 - Northville
1961 - Springport
1947 - New Boston
1967 - Green Oak
1954 - Freedom
1954 - Ridgeway Sec 01
1958 - Summerfield
1982 - Albion Scipio 1 South
1982 - Albion Scipio 3 South
1959 - Hanover
1957 - Scipio - Fayette - Moscow
1959 - Tekonsha
1959 - Albion Twp.
1960 - Albion-Pulaski-Scipio Trend
1961 - Macon Creek
1961 - Medina
1959 - Pulaski - Homer Twps.
1984 - Stoney Point
1963 - Blissfield
1986 - Lee Sec 34 (Black River)
1982 - Albion Scipio 2 South
1982 - Albion Scipio 5 South
1986 - Cadmus
1982 - Albion Scipio 6 South
1954 - Northville
1982 - Albion Scipio 4 South
1967-Adams Twp.
1967 - Lee Twp.
1060 - Olivet
1967 - Sheridan Twp.
1971 - Reading
1984 - Albion Scipio 7 South
1997 - Summerfield Sec 19
1985 - Winterfield
1989 - Rattle Run
1999 - Reading, Sec. 25
1997 - Summerfield Sec 07
1943 - Huron
1979 - Henrietta
1979 - Newburg
1942 - Sumpter
1981 - Albion-Pulaski-Scipio Trend
1997 - Hanover Sec 13
YEAR DISCOVERED/FIELD

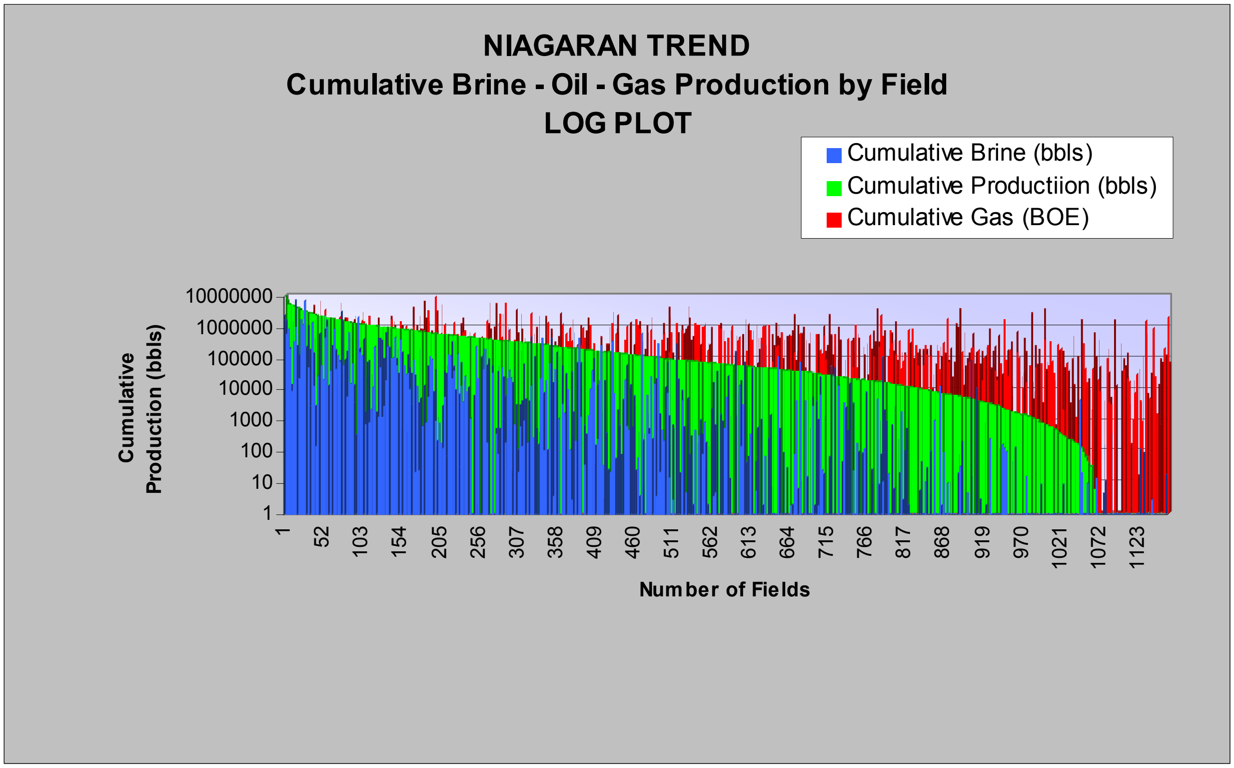

TRENTON - BLACK RIVER TREND
Years of Field Production
v.s.
Cumulative Oil
LOG PLOT
Years of Production
Cumulative Oil Production (bbls)
Cumulative Gas Production (BOE)
YEARS OF PRODUCTION v.s. CUMULATIVE OIL/GAS PRODUCTION
1000000000
100000000
10000000
1000000
100000
10000
1000
100
10
1
1935 - Deerfield
1954 - Northville
1961 - Springport
1947 - New Boston
1967 - Green Oak
1954 - Freedom
1954 - Ridgeway Sec 01
1958 - Summerfield
1982 - Albion Scipio 1 South
1982 - Albion Scipio 3 South
1959 - Hanover
1957 - Scipio - Fayette - Moscow
1959 - Tekonsha
1959 - Albion Twp.
1960 - Albion-Pulaski-Scipio Trend
1961 - Macon Creek
1961 - Medina
1959 - Pulaski - Homer Twps.
1984 - Stoney Point
1963 - Blissfield
1986 - Lee Sec 34 (Black River)
1982 - Albion Scipio 2 South
1982 - Albion Scipio 5 South
1986 - Cadmus
1982 - Albion Scipio 6 South
1954 - Northville (Gas Storage)
1982 - Albion Scipio 4 South
1967-Adams Twp.
1967 - Lee Twp.
1060 - Olivet
1967 - Sheridan Twp.
1971 - Reading
1984 - Albion Scipio 7 South
1997 - Summerfield Sec 19
1985 - Winterfield
1989 - Rattle Run
1999 - Reading, Sec. 25
1997 - Summerfield Sec 07
1943 - Huron
1979 - Henrietta
1979 - Newburg
1942 - Sumpter
1981 - Albion-Pulaski-Scipio Trend
1997 - Hanover Sec 13
YEAR DISCOVERED/FIELD

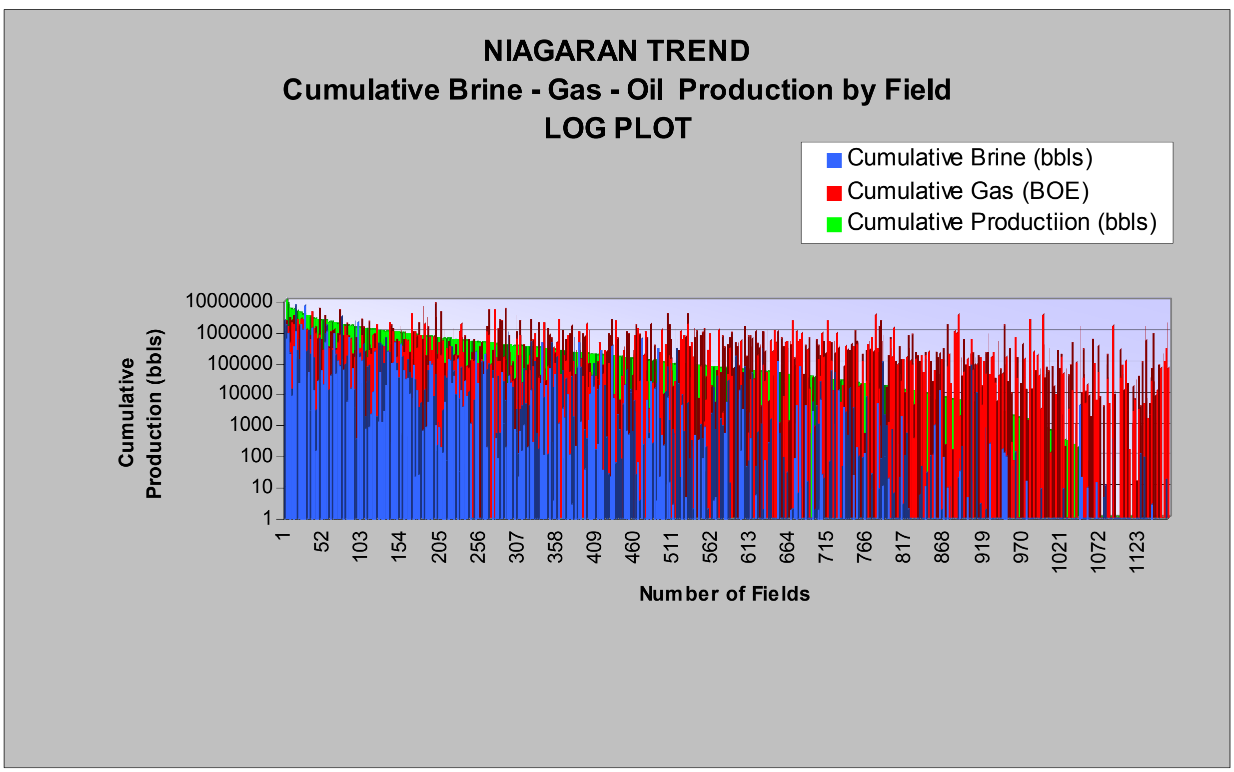
Silurian Niagaran Trend
Production Analysis Graphs

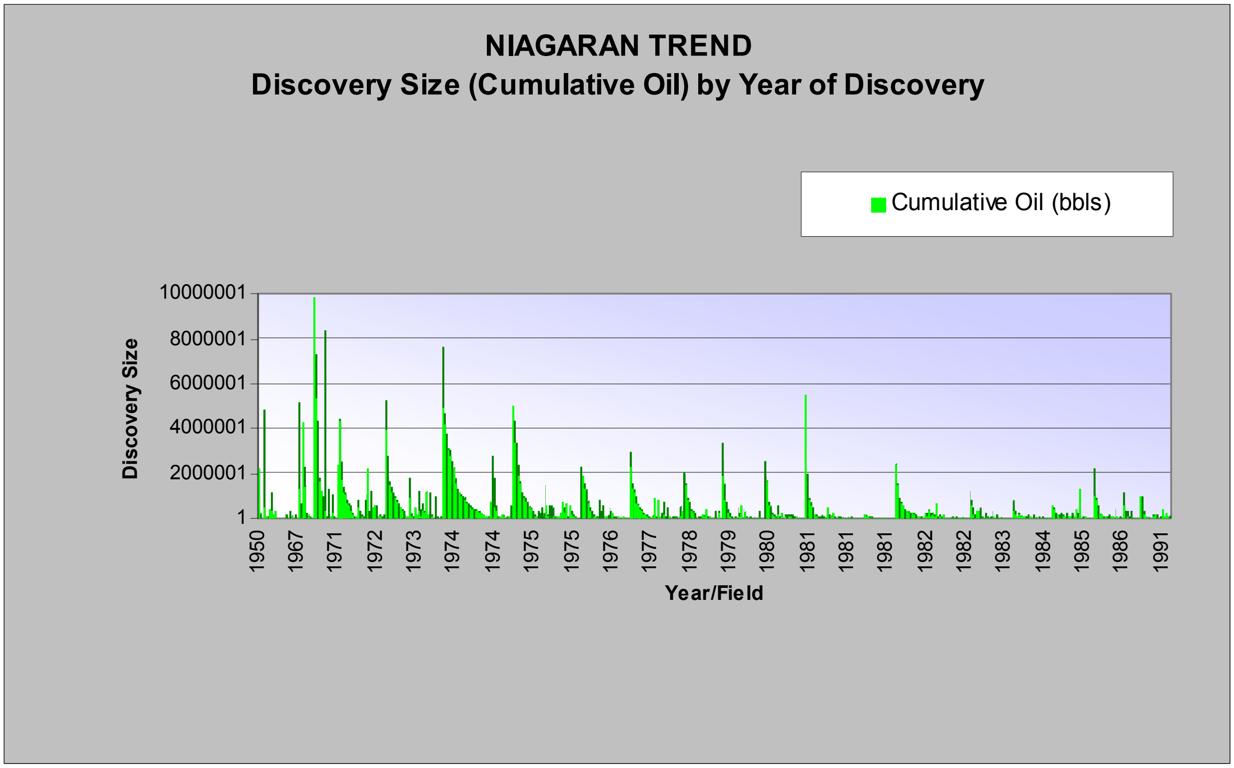


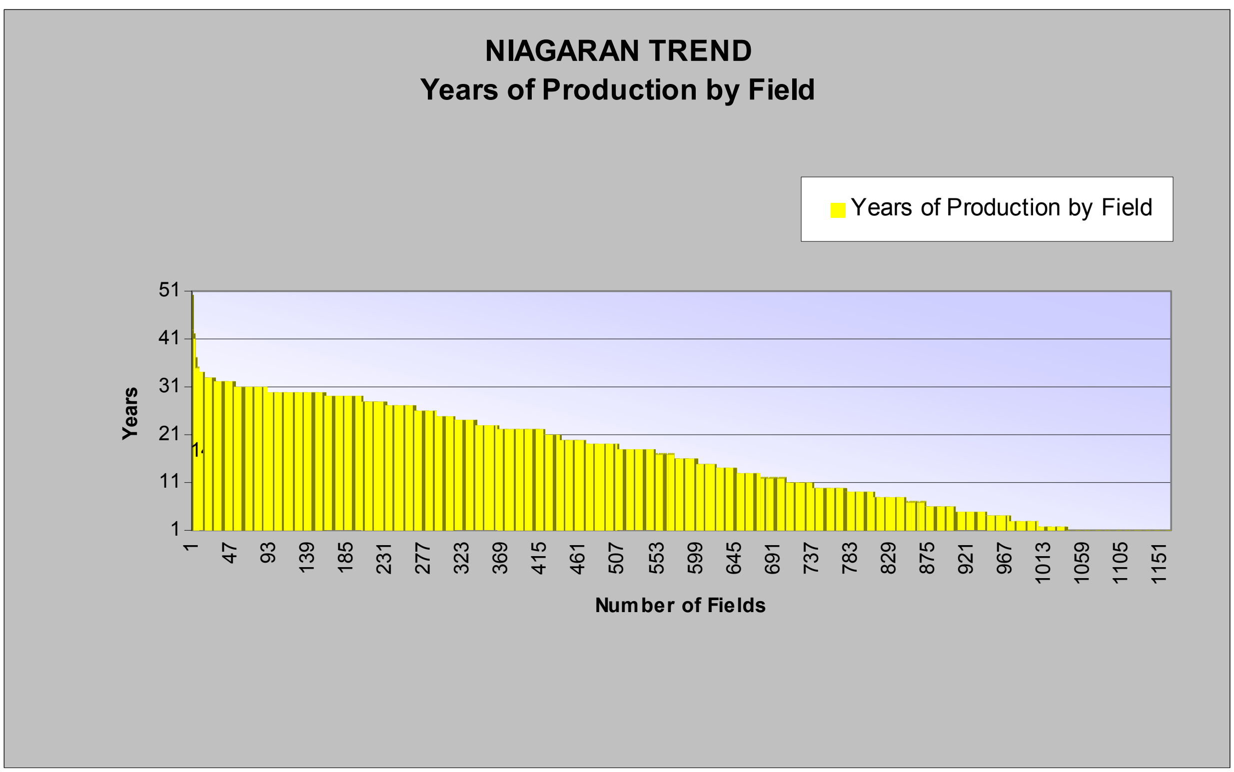

NIAGARAN TREND
Cumulative Gas Production by Field
LOG PLOT
Cumulative Gas (BOE)
Cumulative Production (BOE)
10000000
1000000
100000
10000
1000
100
10
1
1
52
103
154
205
256
307
358
409
460
511
562
613
664
715
766
817
868
919
970
1021
1072
1123
Number of Fields

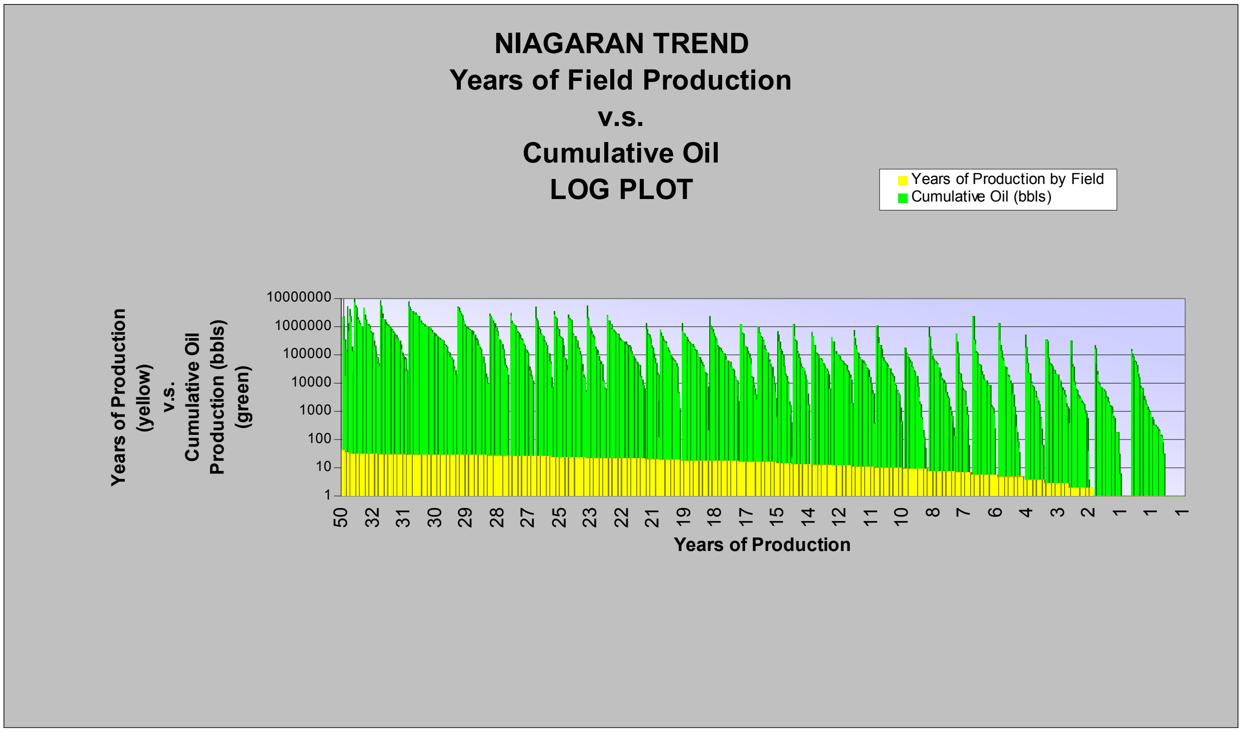

NIAGARAN TREND
Cumulative BRINE Production by Field
LOG PLOT
Cumulative Gas (BOE)
Cumulative Production (bbls)
10000000
1000000
100000
10000
1000
100
10
1
1
52
103
154
205
256
307
358
409
460
511
562
613
664
715
766
817
868
919
970
1021
1072
1123
Number of Fields


NIAGARAN TREND
Cumulative Brine - Oil - Gas Production by Field
LOG PLOT
Cumulative Brine (bbls)
Cumulative Productiion (bbls)
Cumulative Gas (BOE)
10000000
1000000
100000
10000
1000
100
10
1
Cumulative Production (bbls)
1
52
103
154
205
256
307
358
409
460
511
562
613
664
715
766
817
868
919
970
1021
1072
1123
Number of Fields

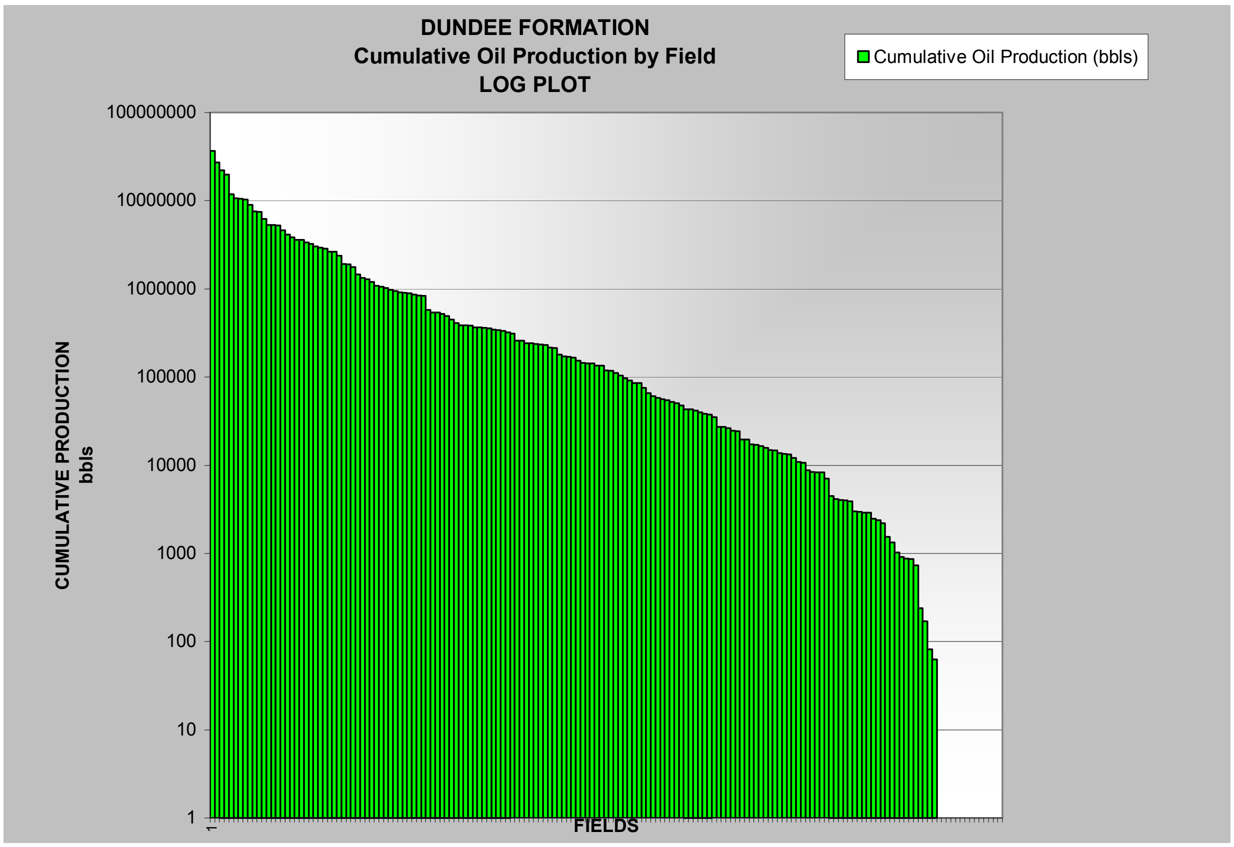

NIAGARAN TREND
Cumulative Brine - Gas - Oil Production by Field
LOG PLOT
Cumulative Brine (bbls)
Cumulative Gas (BOE)
Cumulative Productiion (bbls)
10000000
1000000
100000
10000
1000
100
10
1
Cumulative Production (bbls)
1
52
103
154
205
256
307
358
409
460
511
562
613
664
715
766
817
868
919
970
1021
1072
1123
Number of Fields

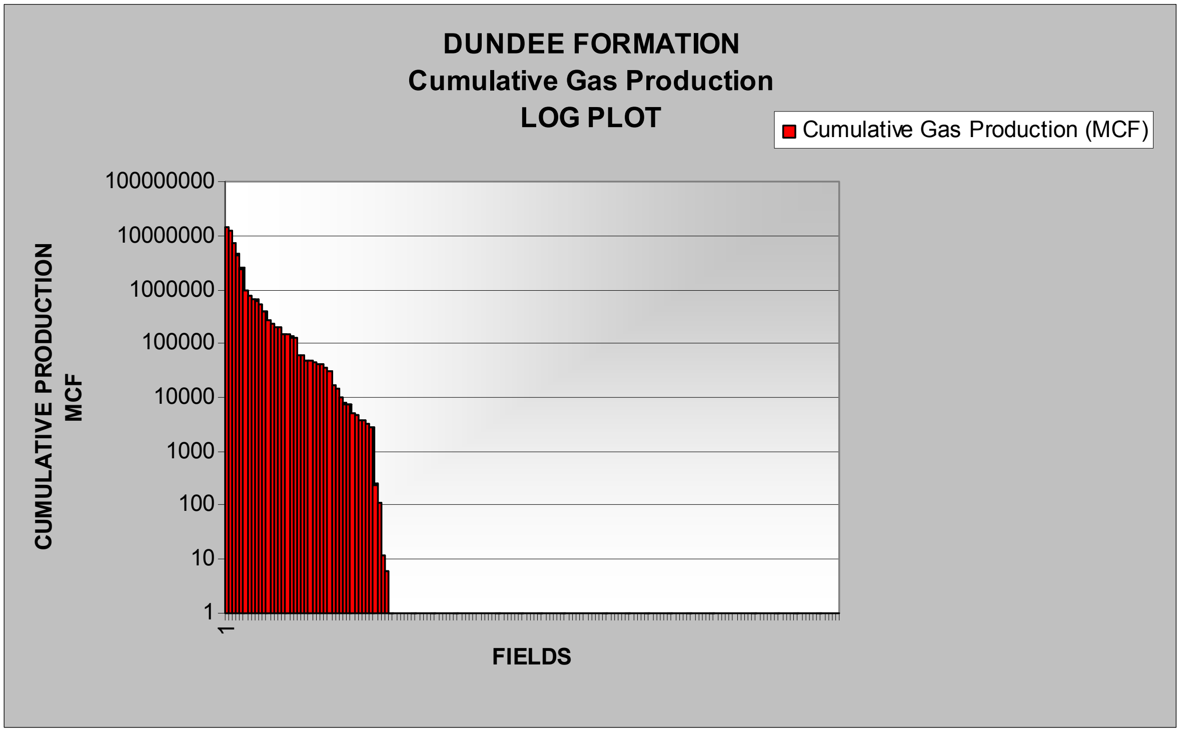

NIAGARAN TREND
Discovery Size (Cumulative Oil) by Year of Discovery
Cumulative Oil (bbls)
Discovery Size
10000001
8000001
6000001
4000001
2000001
1
1950
1967
1971
1972
1973
1974
1974
1975
1975
1976
1977
1978
1979
1980
1981
1981
1981
1982
1982
1983
1984
1985
1986
1991
Year/Field

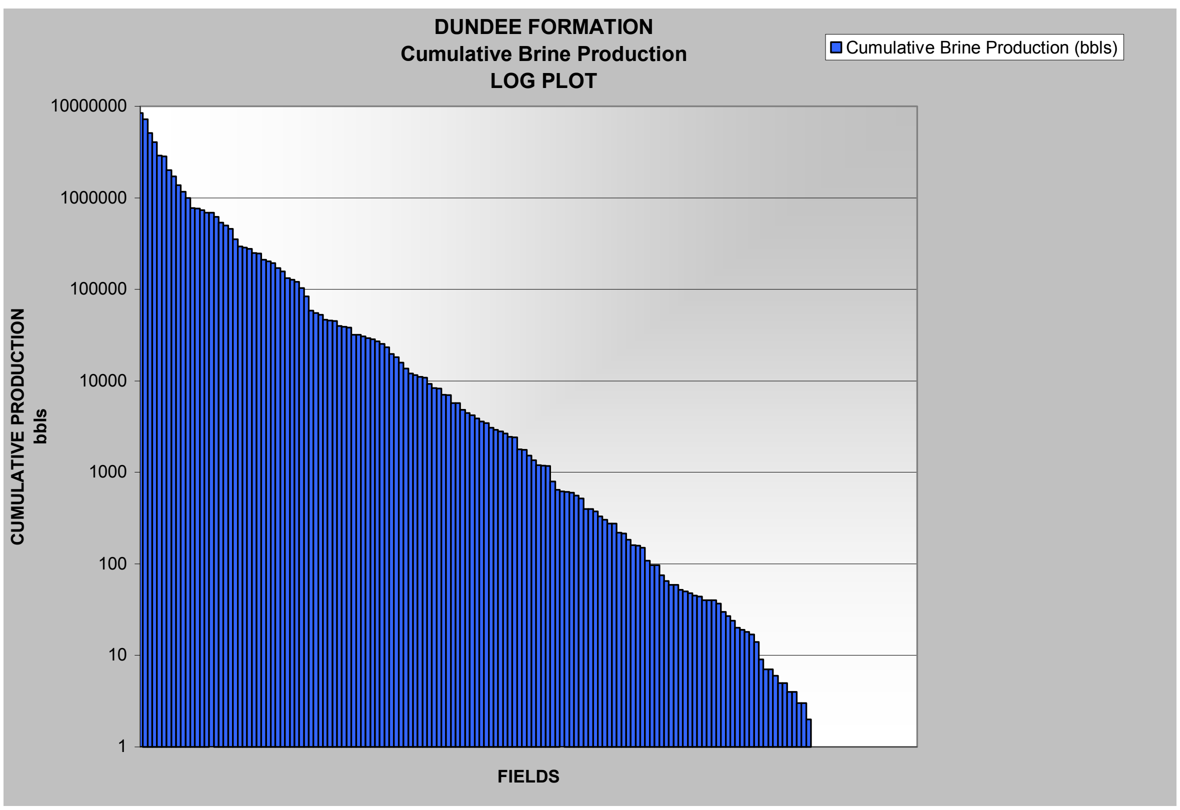

NIAGARAN TREND
Years of Production by Field
Years of Production by Field
Years
51
41
31
21
11
1
1
47
93
139
185
231
277
323
369
415
461
507
553
599
645
691
737
783
829
875
921
967
1013
1059
1105
1151
Number of Fields

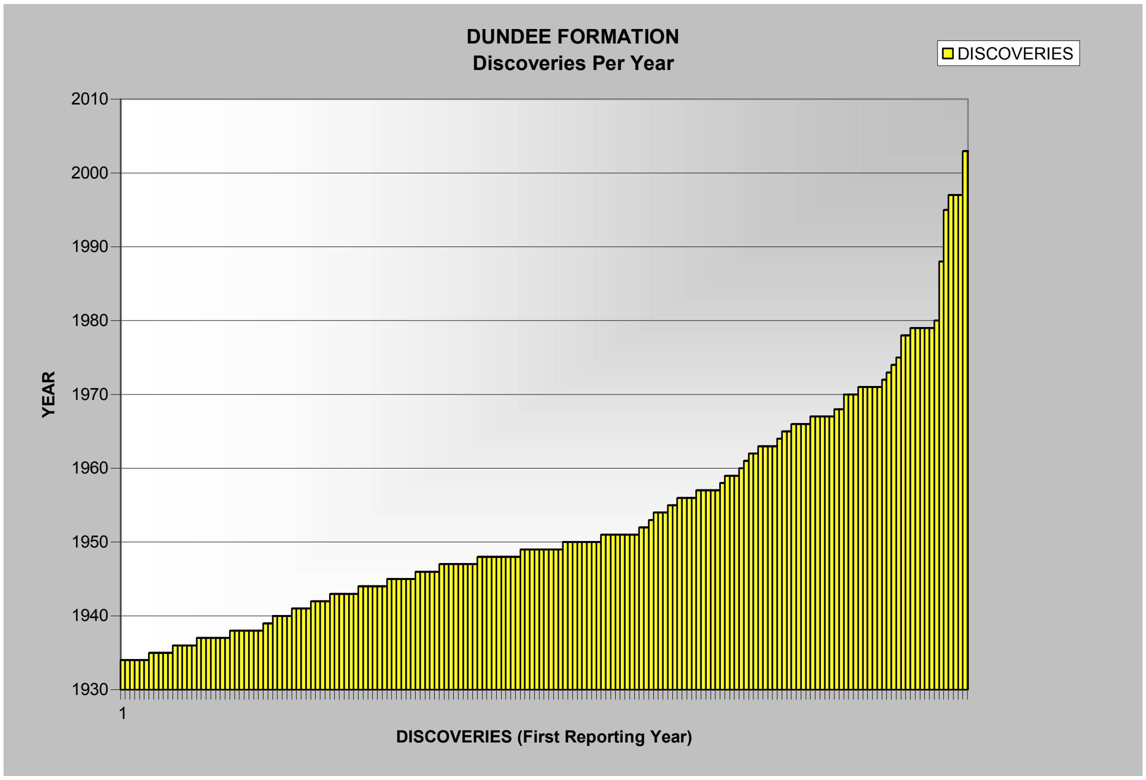

NIAGARAN TREND
Years of Field Production
v.s.
Cumulative Oil
LOG PLOT
Years of Production by Field
Cumulative Oil (bbls)
Years of Production (yellow) v.s. Cumulative Oil Production (bbls) (green)
10000000
1000000
100000
10000
1000
100
10
1
50 32 31 30 29 28 27 25 23 22 21 19 18 17 15 14 12 11 10 8 7 6 4 3 2 1 1 1
Years of Production

Devonian Dundee Trend
Production Analysis Graphs




DUNDEE FORMATION
Cumulative Gas Production
LOG PLOT
Cumulative Gas Production (MCF)
100000000
10000000
1000000
100000
10000
1000
100
10
1
CUMULATIVE PRODUCTION
MCF
FIELDS


DUNDEE FORMATION
Cumulative Brine Production
LOG PLOT
Cumulative Brine Production (bbls)
10000000
1000000
100000
10000
1000
100
10
1
CUMULATIVE PRODUCTION
bbls
FIELDS


DUNDEE FORMATION
Discoveries Per Year
DISCOVERIES
YEAR
2010
2000
1990
1980
1970
1960
1950
1940
1930
1
DISCOVERIES (First Reporting Year)