FOSSIL ENERGY

DOE/BC/15100-2
(OSTI ID: 773383)

ADVANCED CHARACTERIZATION OF FRACTURED RESERVOIRS IN CARBONATE ROCKS: THE MICHIGAN BASIN

Semi-Annual Report
April 1, 1999-September 31, 1999

By
James R. Wood
William B. Harrison

Date Published: January 2001

Work Performed Under Contract No. DE-AC26-98BC15100

Michigan Technological University
Houghton, Michigan

National Petroleum Technology Office
U.S. DEPARTMENT OF ENERGY
Tulsa, Oklahoma

DOE/BC/15100-2
Distribution Category UC-122

Advanced Characterization of Fractured Reservoirs in Carbonate Rocks: the Michigan Basin

By
James R. Wood
William B. Harrison

January 2001

DE-AC26-98BC15100

Prepared for
U.S. Department of Energy
Assistant Secretary for Fossil Energy

Purna Halder, Project Manager
National Petroleum Technology Office
P.O. Box 3628
Tulsa, OK 74101

Prepared by
Michigan Technological University
1400 Townsend Drive
Houghton, MI 49931

TABLE OF CONTENTS

LIST OF GRAPHICAL MATERIAL

ABSTRACT

In year 1 of this project several important project objectives have been attained, including acquisition and digitization of important data sets, analysis of surface fractures over a critical gas and oil field and mapping of basin-scale fracture patterns using literature data. In addition, a strong start was made in writing and testing a project software package, ***Atlas***, that coordinates the digital data in convenient databases and allows the user to graphically it display.

The main objective of this project is to develop a model for fractured carbonate reservoirs based on field data from the Michigan Basin. Accordingly one of the primary tasks was to acquire data from the States 50,000+ gas and oil wells and compile the data in a digital format. The primary data sources in Michigan are paper copies of the original Scout Tickets (17,000+), Driller's Reports and well logs. Over 17,000 Scout Tickets were obtained, scanned and put on CD ROM. Work is in progress on the Driller's Reports, where we have scanned about 50,000 pages out of an estimated 300,000+ pages. All of the scanned images have been attached to ***Atlas.***

Another area where considerable progress has been made is in obtaining copies of the USGS DEM (Digital Elevation Models) for the State of Michigan at the 1/24,000 and 1/250,000 scales. These files have been decompressed and we are in the process of converting them to ArcView Grid files. Preliminary analysis of surface fracture patterns using these data sets has been encouraging. Mosaics of the high-resolution files show excellent ground detail that appears to permit accurate mapping of surface lineations as well as geology and structure. This may be a first application of this type for these data.

So far this work verifies the general picture that the general fracture picture in the Michigan Basin is a dominant NW–SE trend with a conjugate NE – SW trend. DEM data supports the gravity data that this trend is related to a deep basement structural trend coincident with the Michigan Basin Gravity High. In one cases studied so far the surface lineations parallel the elongation direction of the field, suggesting that the fracture pattern at depth is manifested at the surface. This has implications for both hydrocarbon exploration and trapping in the Michigan Basin.

EXECUTIVE SUMMARY

The main objective of this project is for a university–industry consortium to develop a comprehensive model for fractured carbonate reservoirs based on the "data cube" concept using the Michigan Basin as a prototype. This project will combine traditional historical data with 2D and 3D seismic data as well as data from modern logging tools in a novel way to produce a new methodology for characterizing fractured reservoirs in carbonate rocks. Advanced visualization software will be used to fuse the data and to image it on a variety of scales, ranging from basin-scale to well-scales.

Results to date include digitizing of well records, detailed mapping of several key fracture-dominated fields (Deep River and N. Adams), writing code for a new software programs ("Atlas"), and acquisition of seismic data. In addition, we have begun negotiations to acquire a 3D seismic survey shot by Marathon Oil Company over Stoney Point Field.

The general fracture picture that is emerging in the Michigan Basin is a dominant NW – SE trend that manifests itself on a field scale and can be mapped in outcrop. The conjugate direction, roughly, a NE – SW trend is also established in some fields. Data (mainly gravity) suggests that this trend is related to a deep basement structural trend coincident with the Michigan Basin Gravity High. This data has been interpreted as evidence for an old rifting episode early in the Proterozoic history of the Basin. The locations and geometries of many gas and oil fields in the central part of the Michigan Basin are consistent with this interpretation: elongated fields oriented NW – SE or SE – NW with many on the margins of the gravity high.

Work is in progress to document this feature on a field scale by mapping the "Top of Porosity" in the Dundee and Trenton Formations. A common practice in Michigan when developing prospects is to map a parameter termed "Top of Porosity", which is essentially the first encounter of the drill bit with diagenetic dolomite. This parameter is recorded in records (scout tickets and driller's reports that have been digitized as part of this project) for several of the carbonate units in the Michigan Basin, including the Dundee and Trenton Formations. In many reservoirs, the main pay zone is altered limestone that occurs off structure. Most of these traps are classified as stratigraphic. The main dolomite zone is typically 4-6 miles long, striking NW with typical widths of no more than ½ mile. The dolomite is clearly secondary and is finely crystalline and vuggy. In core the dolomite is massive with sporadic vugs lined with small dark brown crystals and larger white rhombic crystals. Vugs are approximately 1 ½ inches in diameter and as much as 5 inches long. There is no evidence of a measurable dip to the dolomite zone and it is assumed to be vertical. Many of the wells examined to date were drilled with cable tools and generally flowed oil on the first few feet of penetration, occasionally out of control. Dolomitization is generally attributed to hot (?) brines ascending from below along joints and fractures. Parts of the Dundee Formation may have been subaerially exposed prior to the deposition of the overlying Bell Shale and may have had a extensive karstic topography developed on it.

INTRODUCTION

Carbonate rocks have been selected for this study because in many basins worldwide, fractured carbonate zones form important oil and gas reservoirs. Termed "dolomite chimneys", in the Michigan Basin, they have long been among the most prolific producers of hydrocarbons in the world. However, key aspects of their origin(s), distribution and architecture have been enigmatic. They have been difficult to find and once found, many have proven difficult to produce efficiently. The Michigan Basin is well suited to serve as a model for fractured reservoirs. It is a mature basin that contains almost 50,000 gas and oil wells with extensive data and rock samples. Over 150 million barrels oil has been produced from fractured carbonate reservoirs in Michigan and adjacent states. The Dundee Formation alone has produced over 350 million barrels, approximately 40-50 million from fractured, dolomitized reservoirs. It has been estimated that nearly this amount of hydrocarbons remains to be recovered.

The data collected and the data cube itself will be on the Internet in digital form together with the software packages required to display and manipulate the data. The software will permit visualization and interpretation on both large and small scales. The main deliverable will be a data cube for the Michigan Basin that will include:

- A library of formation tops picks (300,000+)
- digitized well locations (latitude & longitude; 50,000+)
- scanned images of well header records
- digitized and interpreted logs of key wells
- hydrocarbon logs,
- engineering data, and
- key horizons picked from 2D & 3D seismic data, if possible.

The basin model will be developed in ER Mapper. Detailed case histories and tutorials will be provided. Sponsoring organizations include: Marathon Oil Company, Chartwell Properties, L.. L. C., Advanced Hydrocarbon Stratigraphy, Newstar Resources, Dart Energy and Baker Atlas Logging Services.

RESULTS AND DISCUSSION

Task 1. Project Management

Subtask 1.1 Technical Aspects

Project management continues to operate smoothly: links have been established between the main Michigan Tech operations site and the satellite sites in Kalamazoo, Traverse City and Tampa FL. The promised minimum of 2 face-to-face meetings with all personnel has been held, two meetings in Traverse City, one each in Kalamazoo and Tampa. All senior team members (Wood, Harrison, Luo, Chittick) attended at the spring

AAPG meeting in San Antonio where a project meeting was convened. Plans for the Fall 1999 and Winter 2000 meetings and task assignments were discussed and agreed on.

Michigan Tech is part of the National InterNet2 program that is essentially a project to upgrade the current Internet by making it faster and with wider bandwidth. Our DOE project has been suggested as one that might make use of the added capabilities, particularly the live conferencing. We will explore opportunities this next period and report on any progress and opportunities.

Subtask 1.2 Financial Reports and Accounting

Project expenditures are proceeding according to plan. All necessary reports have been filed with DOE Pittsburgh.

Task 2. Basin Analysis

Subtask 2.1 Geology

Lineation Analysis

We have discovered that the set of Digital Elevation Models (DEMs) compiled by the USGS (U. S. Geological Survey) are ideally suited for analysis of surface lineations in the Michigan Basin, as well as elements of geological structure and bedrock geology. A DEM is essentially a grid of surface elevations at various resolutions generally taken from the Mylars of old USGS 7.5 Minute and 1o quadrangles, resampled and compiled. Data is in the public domain and is available for most of the U. S.

All of the 7.5-minute quadrangle DEMs for the State of Michigan available on the web from United States Geological Survey (USGS) has been downloaded (over 900). These files were unzipped and placed in named subdirectories on hard disk and CD ROM. About 1/3 of the Lower Michigan DEMs have been loaded into ArcView, converted to ArcView grid files and displayed as mosaics in ArcView. An example is shown in Figure 1. The DEM data reveal linear surface trends (Figure 1) that may reflect subsurface geology. We are currently compiling all of the 7.5 minute DEMs into ArcView grid files for the entire State of Michigan and will make them available on CD ROM as part of the project deliverables.

Some problems with the DEM data that will need to be addressed:

1. The USGS high resolution DEM data set is incomplete, especially in some key areas within the Michigan Basin.
2. Some data is recorded in meters and some in feet. Data is in integer form and rounded to the nearest unit making the metric data inherently less precise than the data in feet.
3. Processing errors apparent in some of the quadrangles tend to "stripe" the digital image in an east west direction.

These problems may be resolved in several ways:

1. The USGS apparently has more data available for sale than exists on their current free ftp site that can be purchased at nominal cost.
2. Private vendors, such as "The GEMI Store" (www.gemistore.com) will fill in the data gaps with high-resolution data in feet at higher cost.
3. Lower resolution 1:250,000 DEM data, which has already been obtained, can be spliced into the mosaic. This would be a last resort.

Also, we contracted with Geologic Data Systems (Denver CO.) to perform a lineament study over Arenac County, Michigan using 1:100,000 LandSat 5 satellite imagery and 1:80,000 aerial photography. As can be seen from Figure 2, Geologic Data Systems was able to pick many lineaments, essentially using aerial photographs. We will compare Geologic Data Systems methodology for determining lineaments with picking lineaments from DEMs and either combine the two methods or adopt one or the other on the outcome of the comparisons.

Basin wide mapping has begun. All Michigan well locations up to 1997 have been input into Arcview and plotted (Figure 3). Formation top data will be examined and corrected as necessary, gridded, loaded into ArcView and displayed as basin and field scale maps. Other data, such as initial production and cumulative production is more appropriately viewed as bubble plots on basin and field scales, to high-light linear trends.

Subtask 2.2 Geophysics

2.2.1 Seismic

Three 2D seismic lines were obtained from Marathon Oil Company near the Crystal Field in Montcalm county (MOC), loaded into GeoQuest and processed in an attempt to elucidate Dundee structure. The seismic data was shot targeting deeper plays and thus has low fold and offset to adequately resolve shallower plays such as the Dundee. From structure maps, isopach maps and initial production bubble plots, it is apparent that the Dundee of the Crystal field was faulted and probably karstified. The low fold and offset coupled with unknown static conditions creates a condition of low signal to noise ratio, making it difficult to resolve the shallow structure and fractured nature of the Dundee in the Crystal field (T. Bulloch, 1999). Bay Geophysical of Traverse City, Michigan has however, indicated that they have exclusive processing techniques, which may be able to resolve shallow low fold structure. This project will attempt to acquire data processed by Bay Geophysical, which resolves shallow structure with 2D data.

2.2.2 Borehole

Newstar Resources (Mike Barratt, personal communication) has agreed to donate 20-30 digital wireline logging suites (including image logs) in the Michigan Basin to Michigan Technological University. These logging suites will be used to determine well to field scale fracture trends. Negotiations are also in progress with other companies to obtain their digital image logs and conventional logs. These logs will be loaded into GeoQuest

(Schlumberger) and/or eXpress (Baker Atlas) and processed to determine fracture density and orientation, lithology, and saturation.

Subtask 2.3 Hydrology

This task as it is scheduled for the 2nd year.

2.3.1 Fluid Pathways

Work has begun on developing an empirical flow model for hydrocarbons in the Michigan Basin based on "show" data acquired from the Scout Tickets, Driller's Reports and Mud Logs (see 2.3.3 below). By "show" data we mean mentions of gas and oil shows recorded on these reports. These data are not normally recorded in digital databases, but we now think that a sufficient number can be obtained that a basin-scale plot would reveal the migration pathways. This type of a flow model, based on hard data, would be more convincing to operators and most likely of more use. In addition, if successful, it would demonstrate the value of plotting this parameter in other basins.

2.3.2 Flow Model

We now propose

2.3.3 Gas and Oil Trapping

The show data discussed in 2.3.1above should point toward known gas and oil fields. Thus the trapping mechanisms may be elucidated as well since we would anticipate that the shows would terminate at seals, which are generally either shales, tight limestone or salt in the Michigan Basin. We will plot the oil and gas shows along with producing oil plays in a three dimensional display to show migration routes and oil and gas trapping mechanisms.

Task 3. Quantification and Mapping (WBH)

Subtask 3.1 Data Acquisition

Data Cleanup and Digitization

Over 17,000 scout tickets have been digitized as TIF images and added to our database. These are all of our currently available scout tickets. We have begun work digitizing driller's reports as multiple page TIF images. Digital well logs are being acquired from oil and gas company donations and in house digitizing. Well locations for the digital images of scout tickets and driller's reports recently added to our database are shown in Figure 4. Recently, over new 5,400 wells were added to our database, bringing the total number of well locations to approximately 54,000.

3.1.2 Gridding

As mentioned in the previous report (April, 1999) progress on the data gridding front has been made in several directions. This problem is sufficiently solved that we will not focus on it any further, except to note where changes or improvements have been made.

3.1.3 Database Management

All data associated with this project to date has been placed into a MS Access database as promised. In addition, all documents related to the project (reports, software, etc.) have also been placed in a digital database that consists of the MS Windows normal file structure. The database can be accessed using ***Atlas***, the software developed at MTU specifically for this project (see below).

Subtask 3.2 Mapping and Visualization

3.2.1 2D Mapping

As stated in subtask 2.1. DEM data is being loaded into ArcView. This data is being combined with cultural data such as rivers and lakes to highlight surface expressions of subsurface geology. When combined with well location data, visual correlation with surface lineaments, water drainage patterns and well locations should be readily apparent. Other cultural data that has been obtained and can be displayed includes: roads, county and township boundaries, railroads, and miscellaneous transportation features (oil pipelines, transmission lines, airports, etc.).

3.2.2 3D Mapping

The 3D code for displaying the gridded data described in 3.1.2 above is finished and ready to be incorporated into the project software library. The code has been written in Visual Basic (VB) and is available for testing.

3.2.3 Reports and Maps

Michigan Atlas - In addition to the DEM data described above, most of the progress for this reporting period has come in the development of the Atlas software. This program is turning out to be a very effective tool for consolidating and displaying the project results. We have begun to release the program to a few selected operators in the Michigan Basin for evaluation and feedback. Atlas can be used effectively to determine if certain data exists for a specific well or a group of wells. Well locations are color-coded indicating which wells have the user-requested data (Figure 5). A detailed summary (30+ pages) of this software will be published in the Annual Report for 1999.

Subtask 3.3 Fracture Analysis (WBH)

Literature data has been compiled on outcrop fractures in the Michigan Basin. Samples for petrographic examination have been collected and are being prepared for petrographic examination. These data will be digitized and plotted. Maps and reports will be available in the 1st annual report.

Task 4 Geochemical Studies

Subtask 4.1 Diagenesis

Work is in progress to retrieve "top of porosity" picks from as many wells as possible. This will be aided by examining the scanned driller's reports, using the program Atlas 3.0. "Top of porosity" was usually noted in fields with producing wells and generally indicates diagenetic dolomite. The difference between the formation top picked before "top of porosity" and "top of porosity" is unaltered limestone cap rock.

Subtask 4.2 Fluid Geochemistry

A database on subsurface fluid chemistry is being compiled for the Michigan Basin as part of a student project. Results will be presented in the annual report. Fluid analyses will be correlated with latitude & longitude and them plotted according to the formation of origin to see if any significant trends or correlations are present.

Subtask 4.3 Hydrocarbons

Work on hydrocarbons will begin the 2nd year of the project.

Task 5. Technology Transfer (WBH & JRW)

Subtask 5.1 Public Outreach

5.1.1 Internet (WWW)

A new Internet site for this project has been constructed on the Michigan Tech server. Additional information and reports will be placed on the Western Michigan site.

5.1.2 Newsletter

Results from this project will be reported in the next annual edition of the MOFRC (Michigan Oil Field Research Consortium) scheduled for fall.

Subtask 5.2 Workshops (WBH)

No workshops for this project have been scheduled. Some results were presented (Wood) at the PTTC workshop organized by Harrison and held in Mt. Pleasant in February of this year.

Subtask 5.3 Meetings

5.3.1 DOE Contractor Meetings

No DOE contractor meetings have been called as yet for this project.

5.3.2 National and Regional Meetings

The initial project results were presented at the April AAPG meeting in San Antonio, Texas. Some results were also presented at a PTTC workshop organized by W. Harrison in Mt. Pleasant, MI in March, 1999. We have plans to present results at the Annual AAPG Meeting this April in New Orleans.

CONCLUSIONS

At the end of the first year, the project is on schedule and has met or exceeded all major goals. Specifically, acquisition of fracture data and digitization of that data is either accomplished (Scout Tickets, USGS DEM files) or well underway (Driller's reports and well logs). The main areas of concern are acquisition of a 3D data set. It now appears unlikely that Marathon will donate their 3D data over Stony Point although we will continue to pursue that possibility. It is more likely that we will be able to obtain a 3D data set elsewhere. Also, acquisition of formation scanner logs is proceeding more slowly than we like, but we will make renewed efforts to acquire those data in the second year. The general slowdown in the Michigan Oil Industry has impacted these efforts, but with the rising prices for oil, perhaps operations will return to normal and companies will have more time to work with us and will be more inclined to donate data.

The USGS DEM data sets, particularly the 7.5 minute quadrangles, turned out to be the most promising new development in the project as it now appears that the fractures at reservoir depth have surface manifestations, at least in some cases. We intend to pursue this lead, looking at more fields and over more of the State. We believe that this is one of the first uses of this data for fracture analysis related to gas and oil. With the ready availability of DEM data for the rest of the U.S. this may spark interest in in using the approach in other States.

Development of the ***Atlas*** software is another accomplishment that has exceeded expectations. It is now ready for release as version 3.0 and will be distributed this winter all interested parties, including several downstate companies we have worked closely with on this project. We are hopeful that providing the companies with the Atlas software and the Scout Tickets database will encourage them to reciprocate.

Future activities scheduled for the 2nd year included continuation of the data acquisition, analysis of the DEM data in conjunction with the subsurface data and refinement of the ***Atlas*** software. In addition, we will start to look at the problem of hydrocarbon maturation and migration in the Basin using the gas and oil show data. It will be necessary to compile this data in a digital form, first by processing the Scout Tickets and then the Driller's Reports. We will present the progress to date at the Annual AAPG meeting in New Orleans this April and plan to distribute the Atlas software on a CD ROM at that meeting. We have found that this meeting is a useful forum for publicizing our efforts as well as obtaining useful feedback and ideas.

Finally, the rise of the Internet and its widespread acceptance in the gas and oil industry has caused us to reconsider our Technology Transfer activities. We are now planning for a wider presence on the Web for the project and are looking at ways to provide access to the rather large databases via the Web. We also need to be more concerned with publicizing the project and the Web site.

REFERENCES

"Oil and Gas Fields of the Michigan Basin" 1968, Vol. 1, Michigan Basin Geological Society, M. S. Wollensak, Ed., Department of Geological Sciences, Michigan State University, E. Lansing, MI.

"Oil and Gas Fields of the Michigan Basin" 1968, Vol. 2, Michigan Basin Geological Society, M. S. Wollensak, Ed., Department of Geological Sciences, Michigan State University, E. Lansing, MI.

Bulloch, T., The Investigation of Fluid Properties and Seismic Attributes for Reservoir Characterization: M.S. thesis, Michigan Technological University, Houghton, Michigan, 113p.

FIGURE CAPTIONS

Figure 1. Mosaic of Bellaire, Mancelona, Leetsville and Westwood USGS 7.5' DEM quadrangles (10 meter) with and without lineament interpretations. Center map denotes location of quads. Image on the left hand side of the page is an uninterpreted hillshade relief (sun azimuth 315°, sun height 45°) image. Image on the right hand side of the page has linear features marked. The linear features may be surface expression of subsurface features seismically reactivated over time.

Figure 2. Geologic Data Systems Lineament Interpretation Map of Deep River Township, Arenac County, Michigan with wells from the Deep River Oil & GasField overlaid. NW-SE lineaments parallel the elongated and narrow Deep River field. NE-SW lineaments cut across the field at nearly 90° angles. Evidence seems to suggest that surface lineaments are expressions of subsurface faults or movement along faults in the recent geologic past.

Figure 3. Michigan Oil & Gas Wells drilled prior to 1997. Note the NW-SE linear trend of many of the fields. The linear trend nearly parallels a gravity high running down the center of the state. This suggests that basement control might be largely responsible for oil migration paths and accumulations within the Michigan basement.

Figure 4. Locations of wells that have scanned TIF images of scout tickets and driller's reports recently added to the project database. Accessed from the map based program Atlas, these TIF images have already proven valuable. They have provided a quick means to QC data in a digital database. The alternative method to checking the data is to leaf through volumes of paper records, which is tedious and time consuming.

Figure 5. Print out from Atlas 3.0 showing well locations, roads, rivers, lakes and towns in Isabella County. Wells are color coded to signify presence or absence of user selected data. The current view shows available well locations. The lighter color or red wells indicate well locations that contain scout ticket information. To access the scout ticket information, one merely has to draw a box around the desired wells; a list of permit numbers of the chosen wells is then displayed. By clicking on the permit number of the desired well(s) the TIF image of the scout ticket will be displayed on the screen. Other types of digital data to choose from are multi-page TIF images of driller's reports and LAS (Log ASCII Standard) well log files.

FIGURES

(separate attachment)

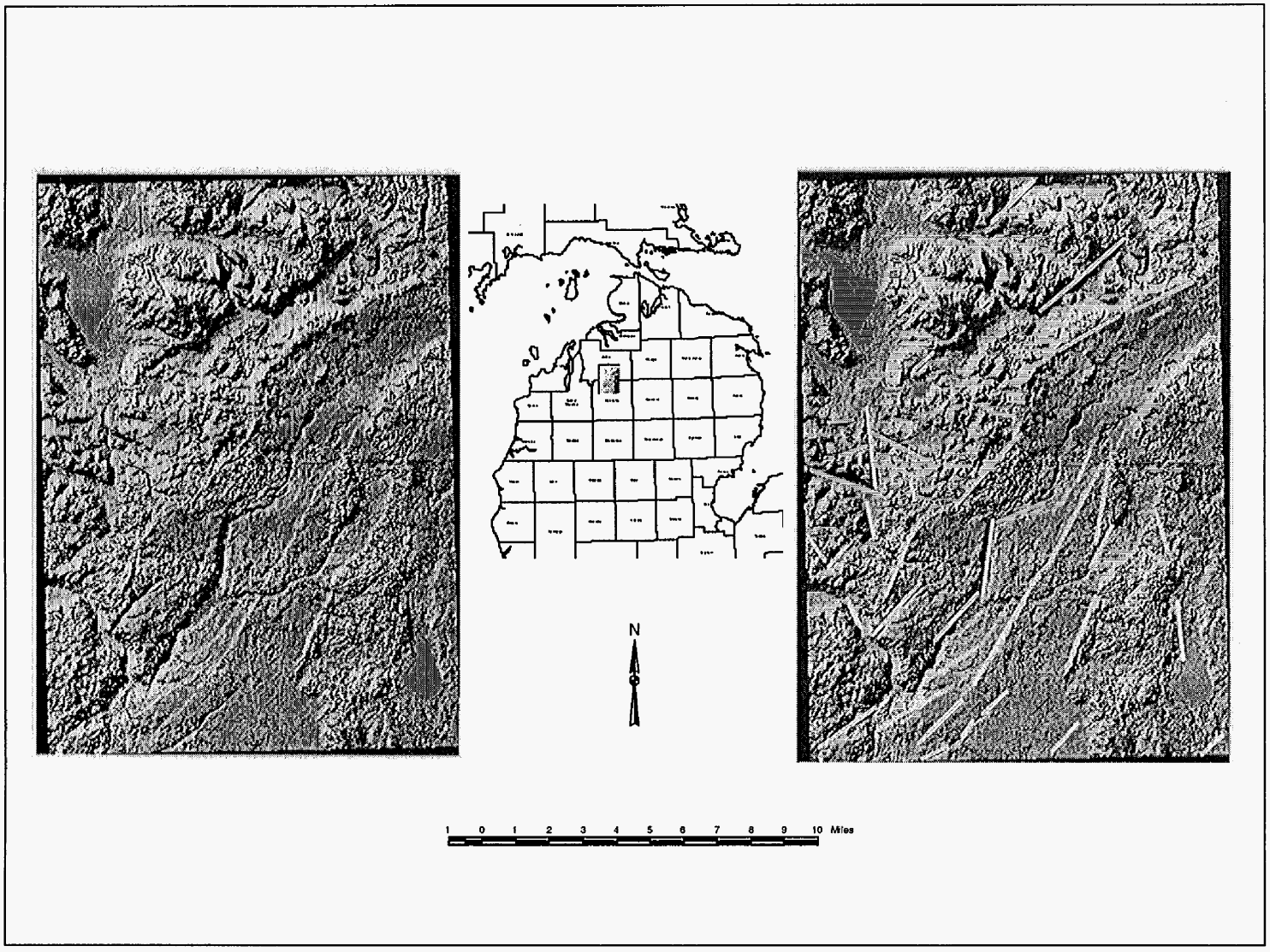

Figure 1. Mosaic of Bellaire, Mancelona, Leetsville and Westwood USGS 7.5' DEM quadrangles (10 meter) with and without lineament interpretations. Center map denotes location of quads.

Composite Fault, Fracture Lineament Map
Deep River Field
Arenac County, Michigan

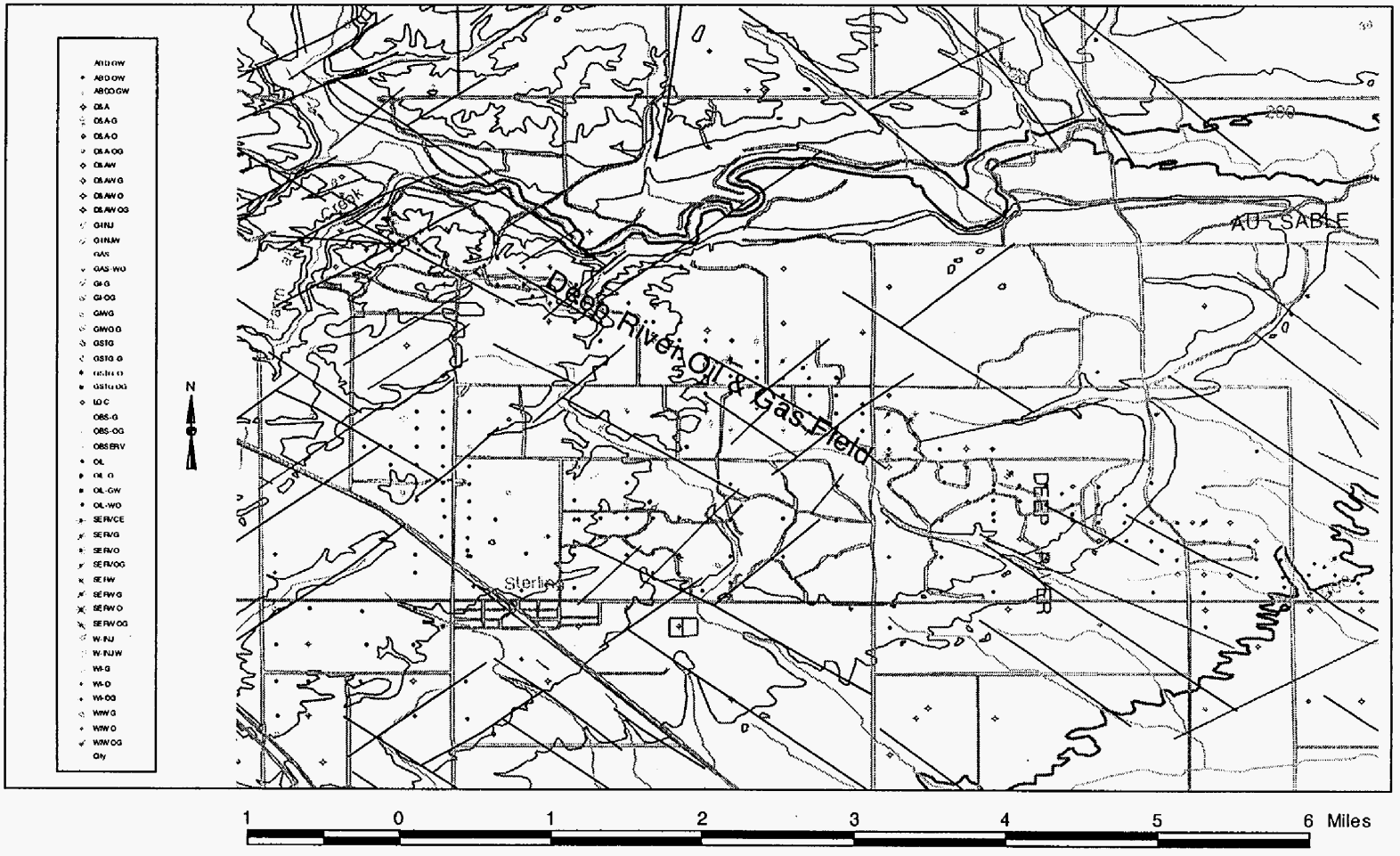

Figure 2. Geologic Data Systems Lineament Interpretation Map of Deep River Township, Arenac County, Michigan with wells from the Deep River Oil & Gas Field Overlaid. Note surface lineaments parallel with the linear profile of the oil & gas field.

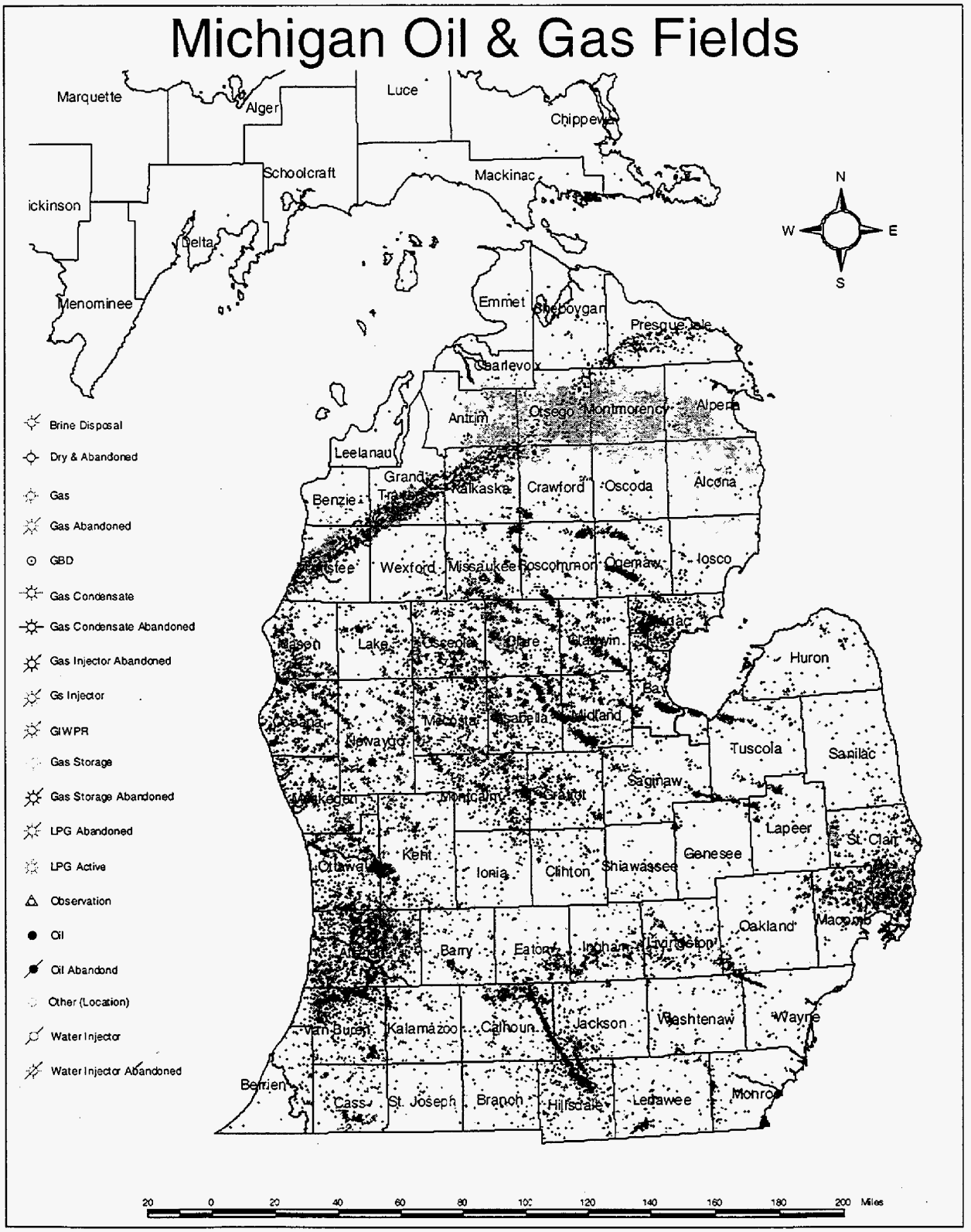

Figure 3. Michigan Oil & Gas Wells Drilled prior to 1997. Note the linear NW_SE trend of the fields.

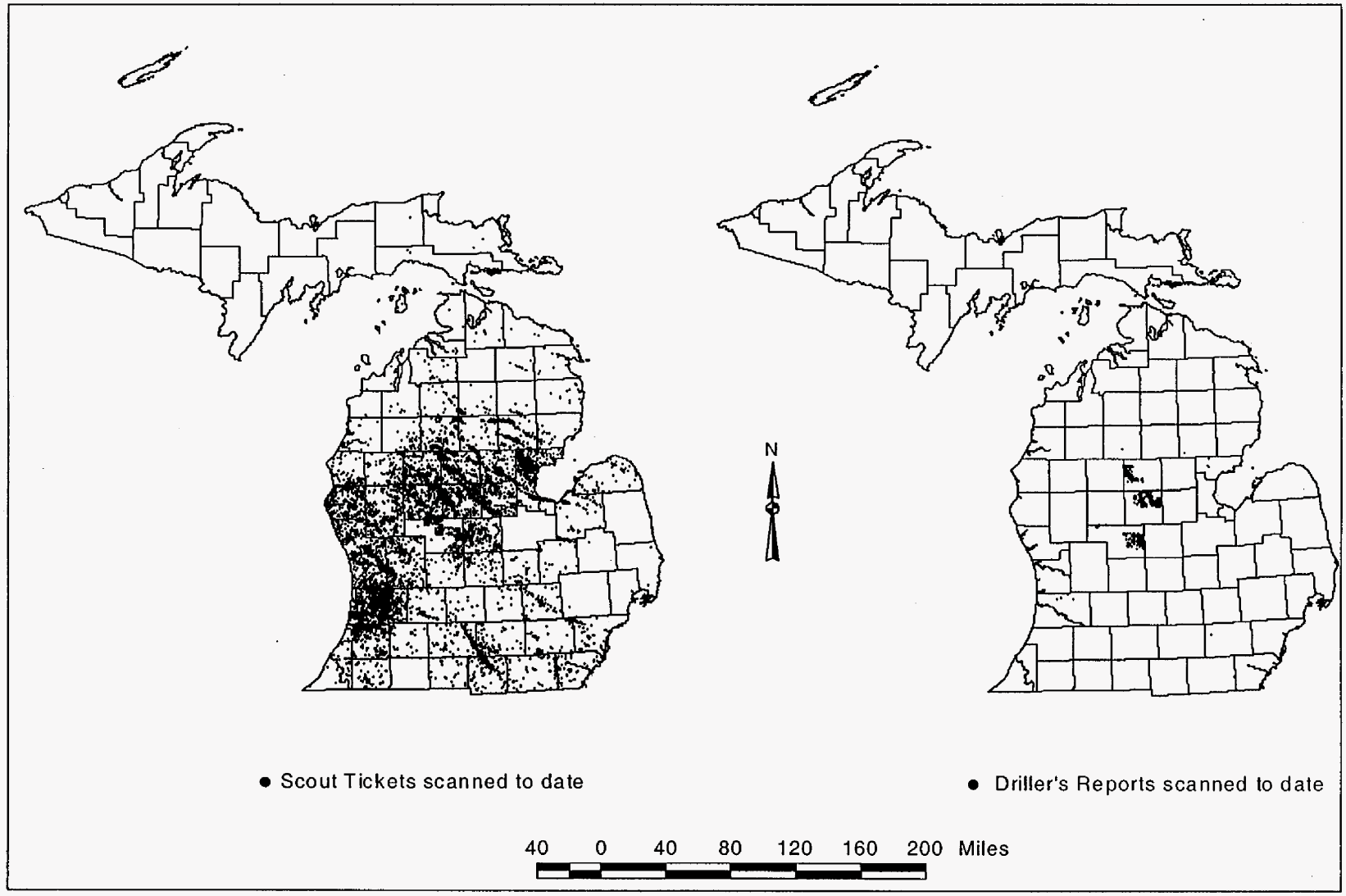

Figure 4. Locations of wells that have scanned TIF images of scout tickets and driller's reports recently added to the project database.

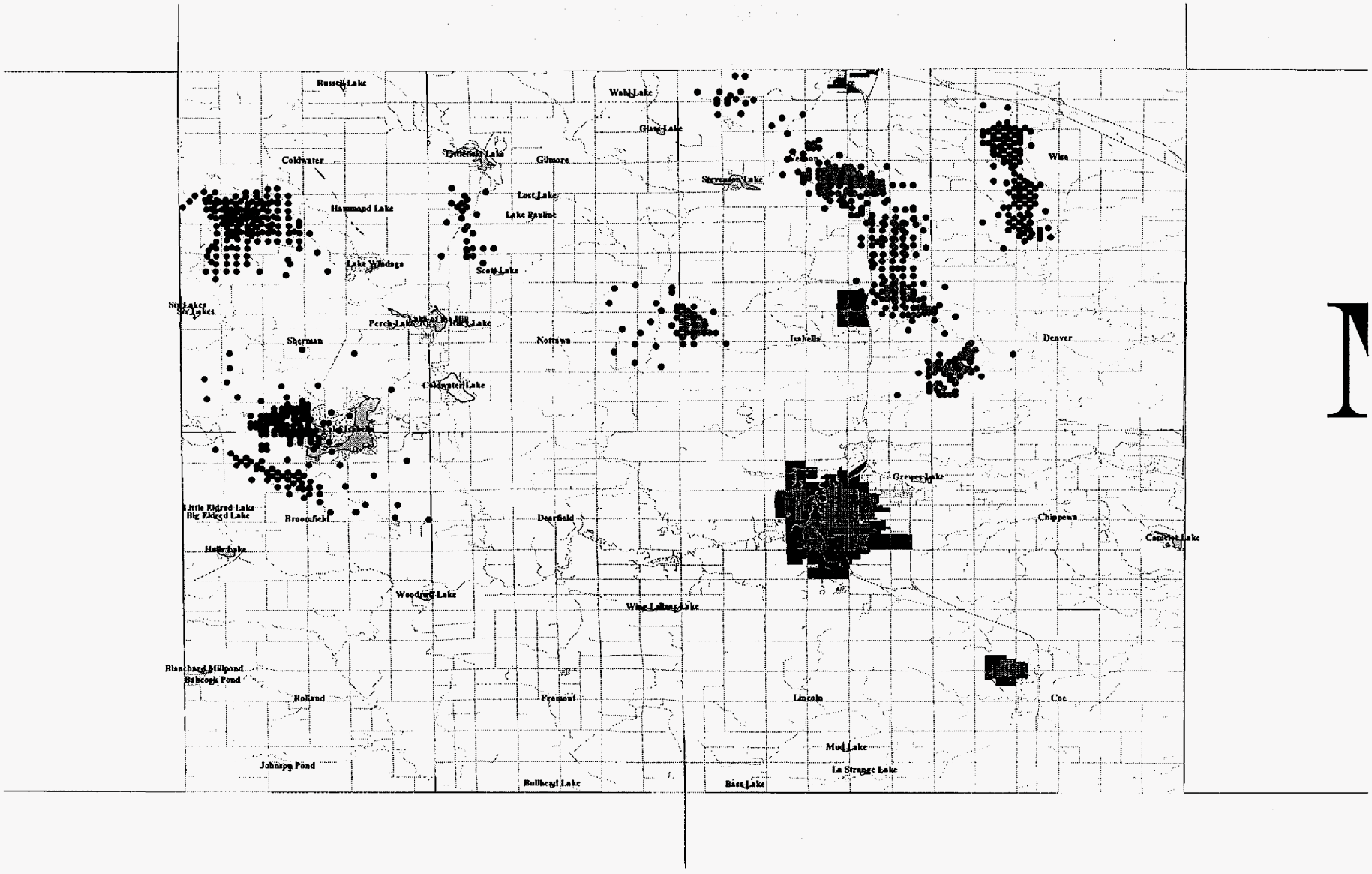

Figure 5. Print out from Atlas 3.0 showing well locations, roads, rivers, lakes and towns in Isabella County. Wells are color coded to signify presence or absence of user selected data.