Mapping and Visualization of Dolomite "Chimneys" in the Michigan Basin

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Introduction

In the Michigan Basin, long, linear dolomitized zones up to ½ mile wide and as much as 5 miles in length constitute major gas and oil reservoirs. These zones have enhanced porosities and permeabilities and have been referred to as dolomite "chimneys". These are nearly vertical features, as far as can be determined by the drill, and are nearly 100% secondary (hydrothermal (?)) dolomite. Good examples are Deep River and N. Adams Fields in Arenac County, Michigan (Figure 1). Under favorable conditions these chimneys are prolific producers of hydrocarbons, typically reaching the 1-10 million-barrel range and occasionally much more, e.g. Albion-Scipio. This type of reservoir is not restricted to Michigan, but is found worldwide in carbonate terrain.

In the Michigan Basin these reservoirs are responsible for at least 50% of the reservoir oil (>300 million barrels) produced from the Dundee and Trenton Formations. They are often heavily fractured and occur either off-structure or cut across structure. One popular model for the Michigan chimneys is that they began to form on carbonate ramps under sub-aerial conditions in a karst environment. The joints were dolomitized by ascending hot saline fluids, which may have debauched onto the surface. Evidence for this includes mud-fills in the host carbonate, fluid inclusion data, diagenetic alteration (dolomitization), and lack of alteration in the overlying rock as well as the gross geometry. This study focuses on mapping and visualizing these unique reservoirs on basin and field scales using non-seismic data sources.

Objective

This report covers the first six months of a 36-month study partially funded by the U. S. Department of Energy to characterize fractures in sedimentary basins. The objective of this study is two-fold: (1) to re-examine the dolomite chimneys in Michigan, particularly with respect to fracture patterns, and (2) to develop tools to examine their spatial patterns and orientations on a basin scale.

The major problem with studying Michigan dolomite chimneys is obtaining data. The dolomite zones are difficult to image seismically, and rarely offer any clue to their presence prior to penetration by the drill. Historically, many of the Michigan fields were found by development drilling once a field had been discovered using conventional techniques. Deep River (Figure 2), for example, was "discovered" by deepening the

overlying Stray gas play down to the Dundee (Rogers City) Formation, discovering production in a small anticline there, and then stumbling onto the productive chimney during development. This was not atypical, and Michigan is fortunate that earlier generations of drillers and well-site geologists were expert in detecting these anomalous features and were diligent in recording their occurrence. What they recorded was the first occurrence of "top of porosity" on their scout tickets and driller's reports. This was essentially the dolomite zone, but was reported as though it was a unique formation top pick. As a result, the data today are archived in hundreds of thousands of paper reports covering drilling activity from the early 1930's to the present. These first had to be located and rendered into a manageable form. Consequently, a secondary objective of this study was to gather the data in a digital form and organize it in databases. Having done that, it was then necessary to develop means of displaying the data. Although commercial software packages (GeoGraphix, GeoQuest, etc.) are available, they are expensive and require considerable training and administrative overhead. It was decided to develop the visualization aspects of the study in ArcView, a standard GIS package that is versatile and affordable. It was also decided to develop a viewer that users could obtain as freeware or shareware to view the results of this project.

Approach

Data Acquisition

Approximately 55,000 wells have been drilled in Michigan through 1998. About 50-60% of these penetrate the main productive carbonate formations, the Dundee and Trenton Formations, so about 25,000 to 30,000 wells reports may contain references to "top of porosity" in dolomite zones. It is necessary to obtain copies of the scout tickets and driller's reports for these wells and then go through them recording formation top picks and mentions of "top of porosity". Sometimes a clue as to the presence of a chimney can be inferred from the geometry of the development wells in a field (Figure 2), but this is not infallible and the only recourse is to manually examine the records. This is complicated by the fact that companies often kept their own records and made annotations that are often the only reference to the dolomite zone. Thus the optimal approach often requires examination of more than one set of reports.

Our approach has been to scan in sets of scout tickets and driller's reports donated by companies, then transfer the data to a digital database. We have included all relevant field information (operator, driller, dates, initial production, permit number, etc.) as well as all reported formation top picks. Progress to date includes complete information on 30+ fields, including over 3000 top picks. Scanned images of 17,000 scout tickets are available and work is in progress on the driller's reports.

In addition to the field data, the USGS (U. S. Geological Survey) has over the years made much of their cartographic (roads, streams, cultural features, etc.) data available in digital form. This includes digital elevation models (DEMs) that show land elevation at various scales. We have obtained all the 1/24,000 (7.5 minute quadrangle data for Michigan, as well as all the 1/250,000 scale DEM data. We are in the process of building mosaics of the 1/24,000 data over the entire lower peninsula to help map fractures and fracture

patterns. The thought is that some subsurface lineations might have surface expressions. We intend to map the surface lineations and then overlay the trends of the dolomite chimneys.

Project Description

As mentioned, common practice in Michigan when developing prospects is to map the "Top of Porosity", essentially the first encounter of the drill bit with diagenetic dolomite. In many Dundee Reservoirs, the main pay zone is altered limestone that occurs off structure. The Deep River Field (Figure 2). is a good example. Here the main reservoir is a diagenetic dolomite lying roughly NW – SE in a trend that is clearly off the structural highs mapped on the Dundee Formation. Tight, unaltered, limestone ("Tombstone") forms a seal. Where the dolomitization has penetrated through to top of the limestone, the overlying Bell shale forms an effective seal. The discovery well was (the Basin Oil Company & Don Rayburn #1) was drilled as an extension to the previously discovered Brea gas field above. Earlier deepening of the Brea gas wells failed to encounter oil and bottomed in tight, non-productive limestone. Deep River Field was eventually found and developed along the dolomite trend and produced over 26 Mbbls. of oil, an average of nearly 25,000bbls per acre, over a period of 56 years from 1943 to present. The maximum number of producing wells was 105 developed on 1060 acres. The average depth to reservoirs was 2800 feet. Porosity averaged 8% with a 60 md permeability. The oil has an API gravity of 35^{o}.

At Deep River, the main dolomite zone is approximately 5 ½ miles striking N 60 W. Detailed mapping (Figure 3) based on development wells shows that it is nowhere more than ½ mile in width. The dolomite strikes along a structural monocline that dips N 30 E and forms the NE flank of the Deep River dome. 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. The dolomitization is known to continue downward at least 260 below the top of the Rogers City (Figure 4). Oil pay was encountered between 1 and 20 feet below the Bell shale and the original wells reported pay thickness of 11 – 12 feet. These wells were drilled with cable tools and generally flowed oil on the first few feet of penetration, occasionally out of control. Subsequent rotary drilling through the dolomite zone placed the OWC at near –2210 feet subsea and found an average pay thickness of 145 feet. The primary reservoir drive mechanism is thought to be a limited water drive primarily because the GORs are low and have remained fairly constant.

New mapping of the Top of Porosity at Deep River shows that the dolomite zone is more complex than previously realized (Figure 5). The primary dolomite zone lies North of structure as previously mapped, but several branches extend at nearly a mile at right angles to the main zone. The dolomitization pattern is clearly more complex than shown on earlier maps, but as before, none of the dolomitization shows any relation to present structure.

A number of fields similar to Deep River are known to exist, and we are in the process of mapping them in detail. Orientations, characteristic widths and lengths and details of the dolomitization are primary objectives. In addition, placing these features in context of the developing Michigan basin is a major objective. This involves collecting subsurface data on a large number of wells and displaying it in convenient forms. At present, ArcView, a commercial GIS software program and an electronic atlas, developed as parts of this project are the main visualization tools.

Results

The principal results of this project so far are the collection of data and the development of a computer program to work with the data. Both data and the program are available upon request form one of the authors (JRW) and both will be augmented and improved over the course of the project.
It is clear that at Deep River the main production is from fracture-controlled secondary dolomite. The orientation follows one of the principal stress directions in the basin and the porosity development is due entirely to the dolomitization.

Application

The goal of this project is to map the distribution of the known dolomite chimneys in the Michigan Basin and relate them to observed surface fracture patterns. Once this is done it may be possible to use the results to locate areas that might be prospective based on similar characteristics. If successful here, the results could conceivably be transferred to other basins where similar plays are known. As mentioned above, dolomite “chimneys” are not restricted to the Michigan Basin, but occur in many other carbonate-dominated basins.

Future Activities

Future activities include completion of data acquisition, including the scanning and archiving of the paper documents detailing the Michigan Basin wells. The ATLAS software package will be further developed to allow interactive editing of data from schout tickets and driller’s reports on-screen. Most importantly, frecture data, particularly on the filed scale, will be compiled and analyzed with respect to chimney orientations and locations. All of these data will be archived and made available to the public on appropriate electronic media, FTP download or CD ROM.

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Figure Captions

Figure 1. Index map for Lower Michigan showing location of Deep River and Adams oil fields in Arenac County.

Figure 2. Surface map of Deep River Field, Arenac County, Michigan showing well locations and section boundaries. The NW-SE trending set of wells outlines the dolomite "chimney".

Figure 3. Detailed structure map of Deep River Field on top of Rogers City Formation. The secondary dolomite trend (labeled) clearly lies off structure. (After MBGS "Oil and Gas Fields of Michigan Basin")

Figure 4. Cross section AA' (see figure 3) across Deep River Field showing stratigraphic relations at Deep River and the narrow dolomite zone between the Bauer #7 and Mutch #2 wells. (After MBGS "Oil and Gas Fields of Michigan Basin")

Figure 5. Contour map of "Top of Porosity" (filled, shaded contours) superimposed on top of structure map contoured on top of Dundee (a.k.a. Rogers City) Formation. The open circles represent IP (initial production) values (bbls/day).

Deep River, Adams, and North Adams Fields, Arenac County

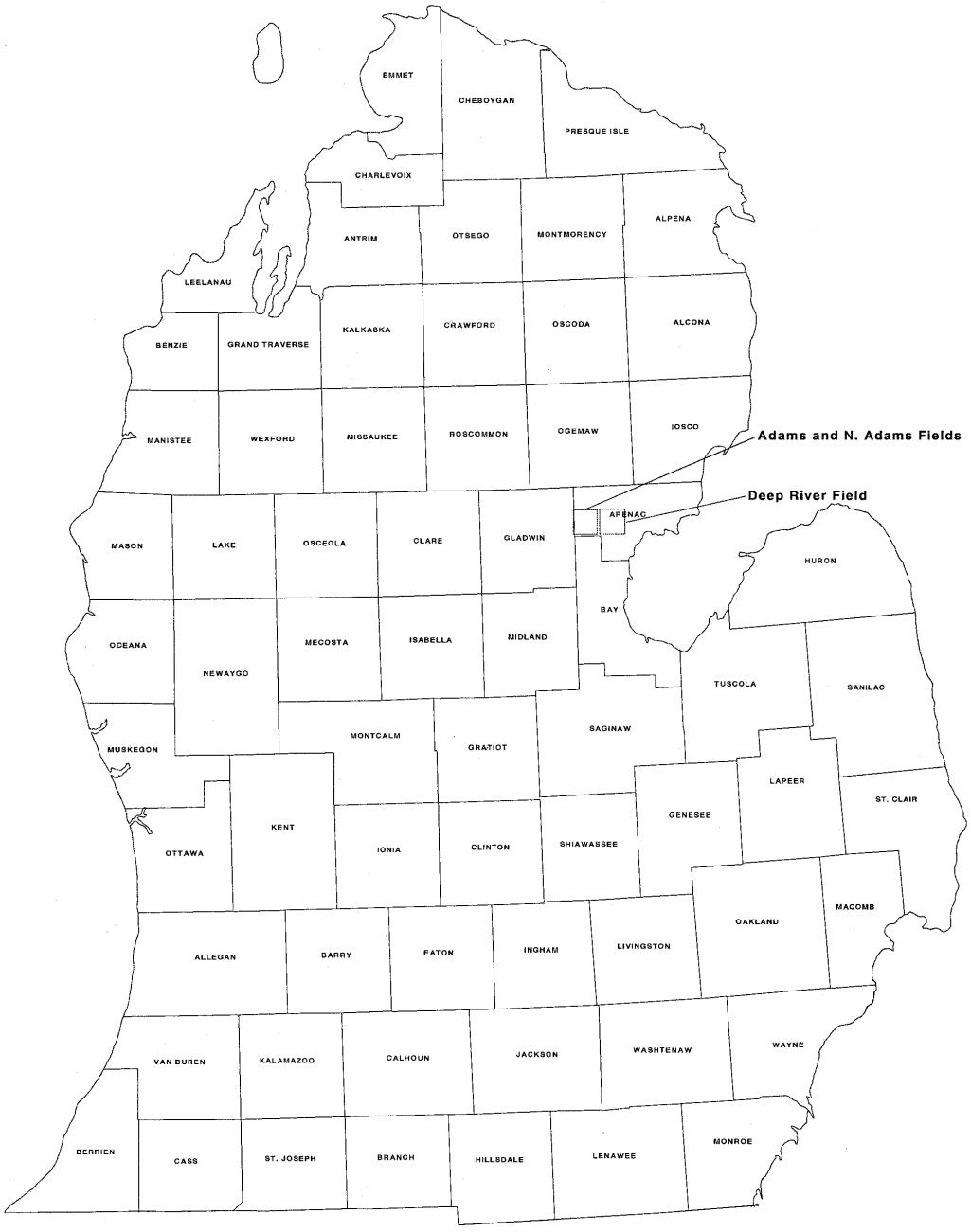

Figure 1.

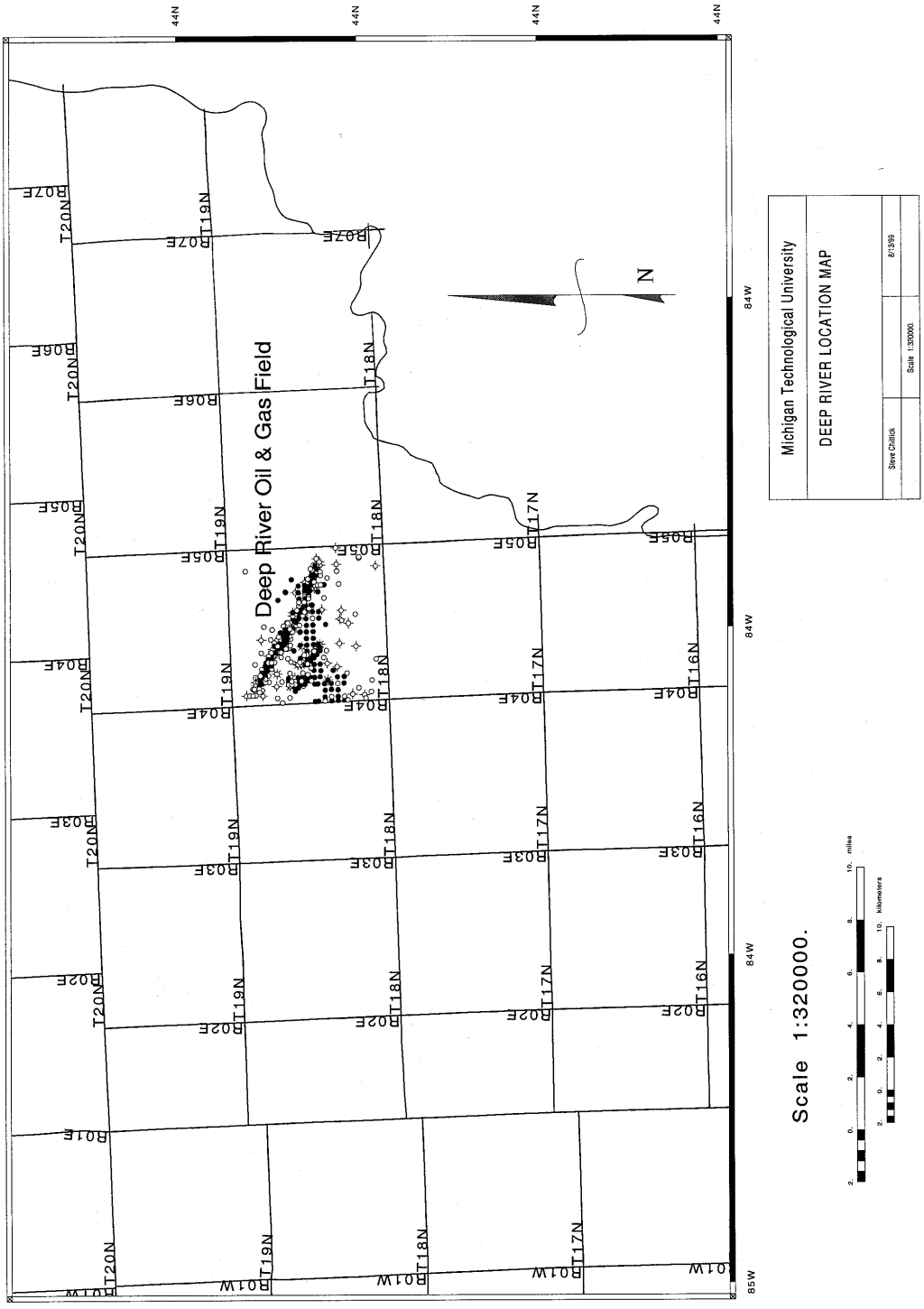
Deep River Oil & Gas Field
Michigan Technological University
DEEP RIVER LOCATION MAP
Steve Chillick
8/1999
Scale 1:320000.
Scale 1:320000.
N
44N
84W
85W
T20N
T19N
T18N
T17N
T16N
R07E
R06E
R05E
R04E
R03E
R02E
R01E
R01W

Figure 2.

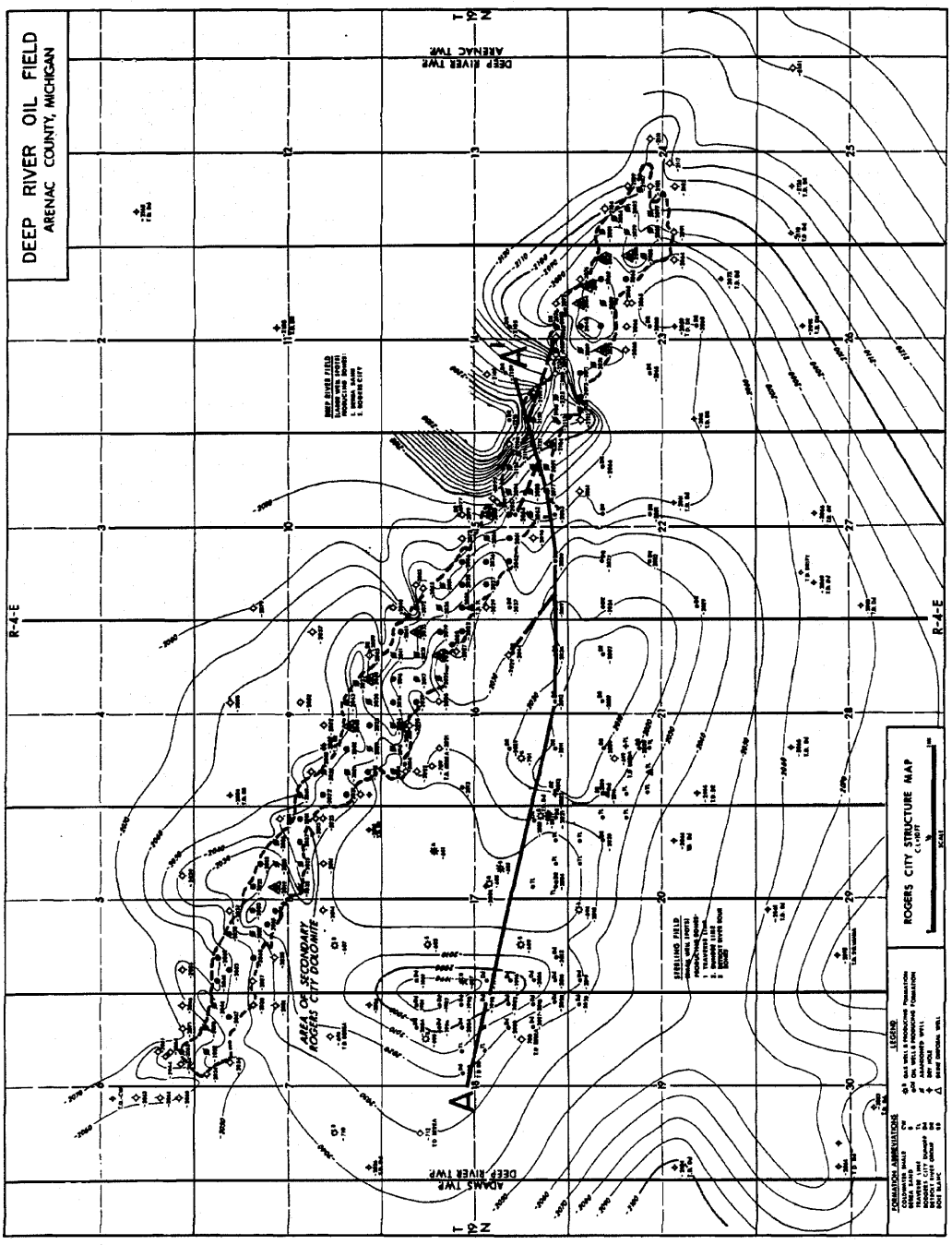
DEEP RIVER OIL FIELD
ARENAC COUNTY, MICHIGAN
ROGERS CITY STRUCTURE MAP
AREA OF SECONDARY ROGERS CITY DOLOMITE
DEEP RIVER TWP
ADAMS TWP
ARENAC TWP
R-4-E
T 23 N
T 24 N
A
A'

Figure 3.

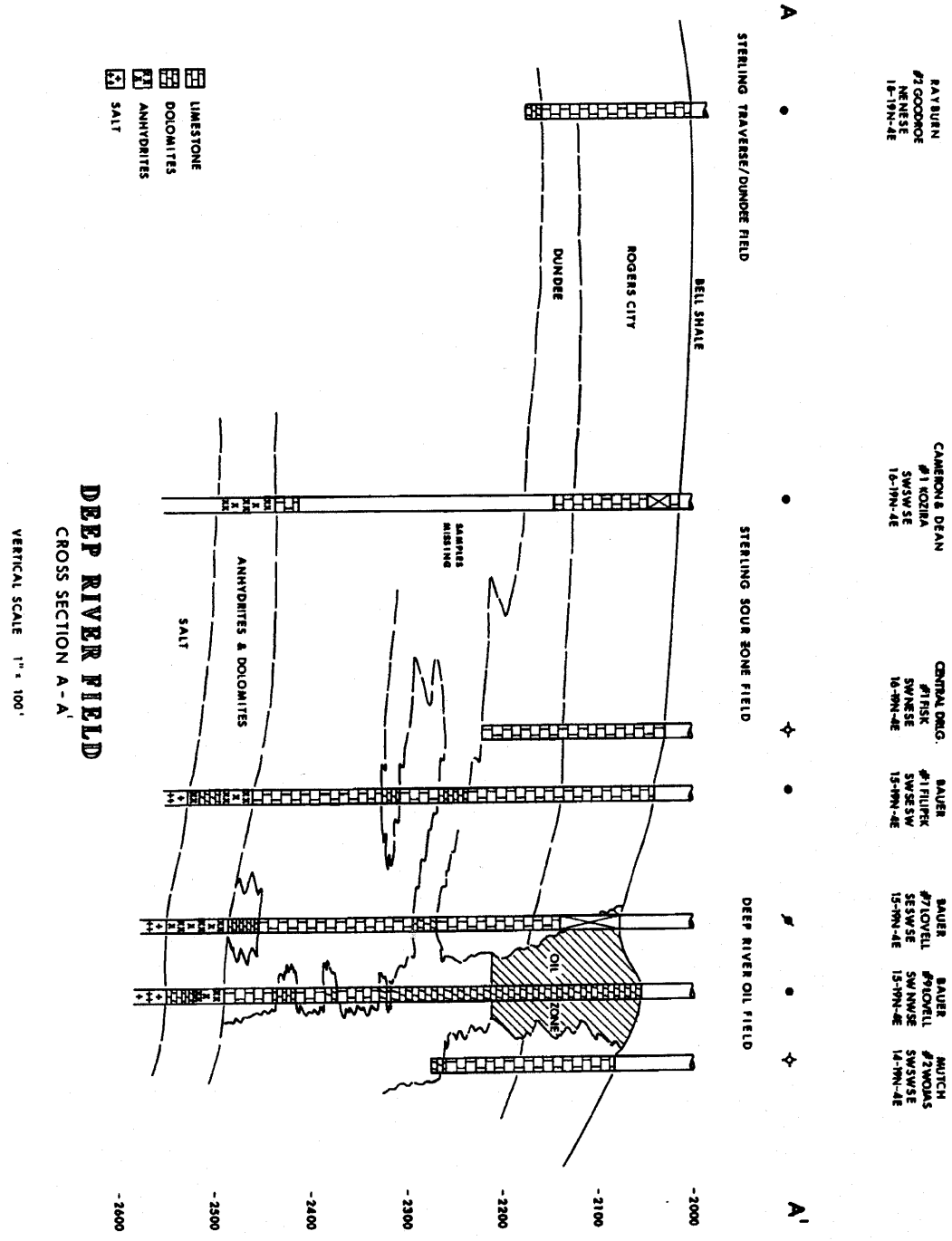
DEEP RIVER FIELD
CROSS SECTION A - A'
VERTICAL SCALE 1" = 100'
LIMESTONE
DOLOMITES
ANHYDRITES
SALT
A
A'
RAYBURN #2 GOODROE NENESE 18-19N-4E
CAMERON & DEAN #1 KOZIRA SWSWSE 16-19N-4E
CENTRAL DRLG. #1 FISK SWNESE 14-19N-4E
BAUER #1 FILIPEK SWSESW 15-19N-4E
BAUER #7 LOVELL SESWSE 15-19N-4E
BAUER #9 LOVELL SWNWSE 15-19N-4E
MUTCH #2 WOJAS SWSWSE 14-19N-4E
STERLING TRAVERSE/DUNDEE FIELD
STERLING SOUR ZONE FIELD
DEEP RIVER OIL FIELD
BELL SHALE
ROGERS CITY
DUNDEE
SALT
ANHYDRITES & DOLOMITES
SAMPLES MISSING
OIL ZONE
-2000
-2100
-2200
-2300
-2400
-2500
-2600

Figure 4.

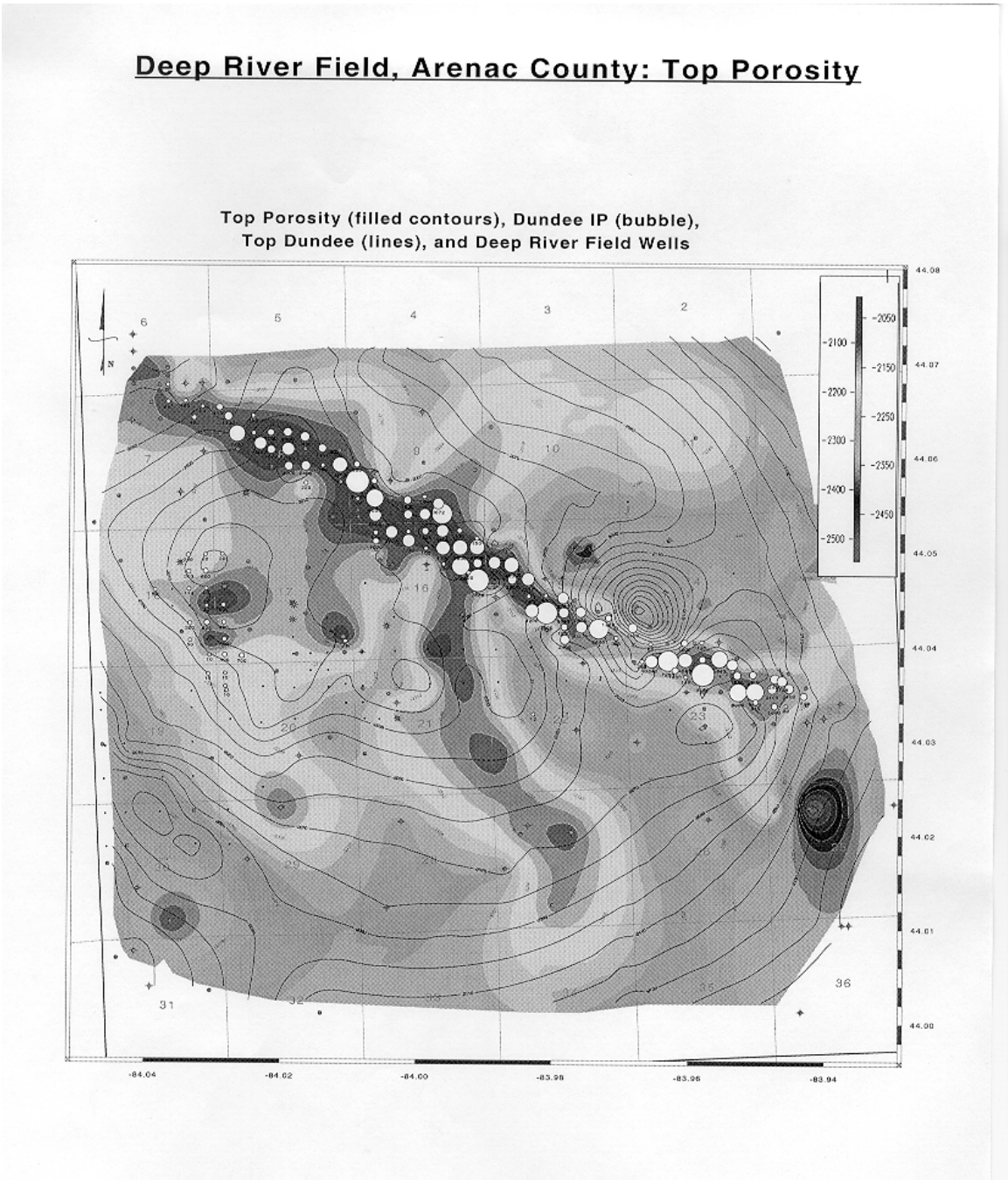
Deep River Field, Arenac County: Top Porosity
Top Porosity (filled contours), Dundee IP (bubble),
Top Dundee (lines), and Deep River Field Wells
-2050
-2100
-2150
-2200
-2250
-2300
-2350
-2400
-2450
-2500
44.08
44.07
44.06
44.05
44.04
44.03
44.02
44.01
44.00
-84.04
-84.02
-84.00
-83.98
-83.96
-83.94

Figure 5.