USING RECENT ADVANCES IN 2D SEISMIC TECHNOLOGY AND SURFACE GEOCHEMISTRY TO ECONOMICALLY REDEVELOP A SHALLOW SHELF CARBONATE RESERVOIR: VERNON FIELD, ISABELLA COUNTY, MI.

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ABSTRACT

One of the main objectives of this demonstration project is to test surface geochemical techniques for detecting trace amounts of light hydrocarbons in pore gases as a means of reducing risk in hydrocarbon exploration and production. As part of the project, several field demonstrations were undertaken to assess the validity and usefulness of the microbial surface geochemical technique. The important observations from each of these field demonstrations are briefly reviewed in this annual report. These demonstrations have been successful in identifying the presence or lack of hydrocarbons in the subsurface and can be summarized as follows:

1. The surface geochemistry data showed a fair-to-good microbial anomaly that may indicate the presence of a fault or stratigraphic facies change across the drilling path of the State Springdale & O'Driscoll #16-16 horizontal demonstration well in Manistee County, Michigan. The well was put on production in December 2003. To date, the well is flowing nearly 100 barrels of liquid hydrocarbons per day plus gas, which is a good well in Michigan. Reserves have not been established yet. Two successful follow-up horizontal wells have also been drilled in the Springdale area. Additional geochemistry data will be collected in the Springdale area in 2004.
2. The surface geochemistry sampling in the Bear Lake demonstration site in Manistee County, Michigan was updated after the prospect was confirmed and production begun; the original subsurface and seismic interpretation used to guide the location of the geochemical survey for the Charlich Fauble re-entry was different than the interpretation used by the operator who ultimately drilled the well. As expected, the anomaly appears to be diminishing as the positive (apical) microbial anomaly is replaced by a negative (edge) anomaly, probably due to the pressure draw-down in the reservoir.
3. The geochemical sampling program over the Vernon Field, Isabella County, Michigan is now interpreted as a large negative anomaly associated with the entire field. The results of the State Smock horizontal well and the Bowers 4-25 well confirmed the lack of additional recoverable hydrocarbons in the Vernon Field.
4. The surface geochemistry data showed a strong anomaly in the Myrtle Beach, Burke County, North Dakota area that would justify drilling by itself and even more so in conjunction with the structural interpretation from the geological and geophysical data; the microbial values here were the highest we have observed. The Myrtle Beach geochemical survey indicated a good to excellent prospect which was confirmed by drilling, however, a pipeline has not yet been completed that would allow the wells to be placed into production.

We also present in this annual report the results of recent efforts to map carbonate facies tracts in the middle Devonian Dundee and Rogers City Limestones using gamma ray, bulk density, and photoelectric effect geophysical well log amplitudes. This work was undertaken to identify fairways for exploration in the Dundee and Rogers City where surface geochemical techniques could then be used to screen potential leads.

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LIST OF GRAPHICAL MATERIALS

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Figure 3. Generalized Stratigraphic Column for the Williston Basin. Black dots are key productive intervals in the Myrtle Beach area.

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Figure 5. Microbial contour map of the Springdale Prospect in Manistee County, Michigan. Red well path is St. Springdale & O'Driscoll 16-16 HD1. Large red circles are bottom hole locations (bhl) of horizontal wells; pink circles are bottom hole locations of deviated wells. Green color filled contours indicate high microbial anomalies and yellow color filled contours indicate low anomalies. The change in the microbial anomaly along the path of the St. Springdale and O'Driscoll 16-16 HD1 may represent a fault or stratigraphic facies change.

Figure 6. Microbial sample location map for the Vernon Field and surrounding area in Isabella County, Michigan. Black triangles are microbial sample locations and the dark gray symbols are well locations.

Figure 7. Microbial sample location map and contour map for the Vernon Field and surrounding area in Isabella County, Michigan. Black triangles are the microbial sample locations. Blue color filled contours indicate high microbial anomalies and yellow color filled contours indicate low anomalies. The entire Vernon Field is a large negative anomaly.

Figure 8. Microbial sample and well location map for the Bear Lake area, Manistee County, Michigan.

Figure 9. Microbial sample location and contour map for Bear Lake, Manistee County, Michigan. Blue contours indicate high microbial anomalies and yellow contours indicate low anomalies. Location of Charlich-Fauble sidetrack is shown by pink line.

Figure 10. Microbial sample locations in the Myrtle Beach area. Microbial counts posted in red below sample location. Black outline is location of 3D seismic survey. Blue lines are rivers and lakes, Green lines are roads, subsea Winnipegosis tops for 3 deep wells posted in red. North is toward top of map.

Figure 11. Microbial contour and sample locations in the Myrtle Beach area. Red and Purple color filled contours indicate high microbial anomalies and green indicates low anomalies. Contour interval is 5 microbial counts. The high microbial counts recorded here are the highest recorded in the project to date.

Figure 12. Location map for 2003 Dundee-Rogers City producing wells (black dots) from the Michigan Department of Natural Resources (MDNR) production database. County names are also shown for reference.

Figure 13. (A) Stratigraphy diagram for the Dundee-Rogers City and surrounding Middle Devonian units from west to east across the central Lower Peninsula of Michigan (modified from Catacosinos et al., 1991). (B) Cross-sectional stratigraphy schematic from southwest toward the center of the basin, illustrating that the Bell Shale, Rogers City and Dundee intervals are all absent in portions of southwestern Michigan. Note that the vertical scale is exaggerated.

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Figure 16. Comparison of four proportional gamma ray, bulk density (rhob) and photoelectric factor (Pef) slices for the Dundee and Rogers City Limestones in the Michigan Basin (refer to Figure 15 for approximate slice locations). Note the subtle North-South trends in the gamma ray and pef slices. The rhob slices show the extent of the Reed City Member (anhydrite). The gamma ray slice data range is 0 to 30 api units and the contour interval for each slice is 3 api units. The rhob slice data range is 2.0 to 3.0 grams per cubic centimeter (g/cc) and the contour interval is 0.07 g/cc. The data range for each Pef slice is 0 to 10 barns per electron (b/e). The contour interval is 0.6 b/e. 300 wells were used in the gamma ray slices, 150 wells were used in the rhob slicing and 121 wells were used in the Pef slicing. Gray lines are county boundaries and gray numbers are county names. North is toward the top of the slices. Large white dots are data control points on each slice. Yellow and black rectangles show the location of the Vernon geochemical survey area.

Figure 17. (A) Slice 19 from the top-down Dundee Limestone results. (B) Taylor's (2001) depositional model for the upper Dundee superimposed onto slice 19 illustrating the similarity between the shelf trend in Taylor's model and the low gamma ray trend from the slicing results.

1.0 EXECUTIVE SUMMARY

New Findings

The project has located hydrocarbons a second demonstration site, the Springdale demonstration area (Figure 1) and the initial wells have begun production. The State Springdale-O'Driscoll #16-16 and the Hebart 12-16 are producing at approximately 100 barrels of oil per day and 100 mcf of gas per day, on average. Production is from the Brown Niagaran (Figure 2) interval. These wells are located on a mild geochemical anomaly (Figure 5). A third follow-up well is planned in the northeast quarter of section 21 early in 2004 and additional wells have been located in Section 16 that may be drilled later in 2004

The preliminary microbial geochemical survey over the new Springdale demonstration site shows an anomaly that suggested the presence of a fault crossing the projected path of the proposed 16-16 horizontal well; the horizontal well bore went from reservoir to non-reservoir rock at approximately this same position.

Lessons Learned

The basic lesson is that geochemical surveys should precede drilling in Michigan prospects. It is difficult to convince companies of the value of conducting surveys, but the results to date have been consistent, only marginal results (e.g. gas/oil) show when the geochemical anomaly is mediocre. Preliminary data from the new Springdale site suggests geochemical surveys may be able to indicate the location of faults or other discontinuities in the subsurface.

However, it appears that geochemical surveys over developed fields have to be interpreted with caution due to the disturbances caused by production (e.g. pressure drawdown) which seem to produce negative or apical anomalies in the vicinity of the well bore extending out at least 1/2 mile. Perseverance and patience are also virtues in this type of exploration, as well as adopting a consistent set of sample procedures.

Should Something Else Have Been Done?

We should have stipulated that all project demonstrations had to have surface geochemistry surveys included in the prospectus, that is, as part of the package used to sell the prospect to investors. This would both educate the gas and oil community as to the value of geochemistry as well as insure that we are notified sufficiently in advance of the drilling to make better sampling plans and have an opportunity to conduct a "fill-in" geochemical survey if the original survey shows gaps and/or holes.

Goals and Results

The goals of this project were to: (1) test the use of multi-lateral wells to recover bypassed hydrocarbons and (2) to access the potential of using surface geochemistry to reduce drilling risk and where possible locate and produce hydrocarbons based upon these surveys.

To date various applications of surface geochemistry have been applied to demonstration areas (Vernon, Myrtle Beach, Bear Lake and Springdale) with good success. The Bear Lake, Springdale and Myrtle Beach surveys indicated good-to-excellent prospects for hydrocarbons which were confirmed by drilling. The Vernon survey indicated poor prospects for hydrocarbons which were also confirmed by drilling.

In the Springdale area of Manistee County two successful horizontal wells have been drilled producing 100 barrels of oil per day (Figure 5). In the Bear Lake area in Manistee County, a successful re-entry lateral (Charlich-Fauble 2-9HD1) was drilled by a Michigan operator and has resulted in a well producing 200 barrels of oil per day. Results from the Bear Lake surface geochemical survey indicated this reef would probably be productive (Figure 9). Two demonstration wells, the State Vernon & Smock 13-23 HD1 and HD1A and the Bowers 4-25 #1, were drilled to test the Dundee formation at Vernon Field for bypassed oil and as predicted by the geochemical survey results, these wells did not find commercial hydrocarbons; several additional geochemical anomalies were discovered in the greater Vernon area that could be further investigated (Figure 7). In the Myrtle Beach area of North Dakota, the two existing wells are still shut-in, waiting on pipeline connections (Figure 11). Surface geochemistry in this area recorded the highest positive microbial anomalies we have obtained so far from our geochemistry sampling program.

Applications

The geochemical program will be focused now on Springdale, probably through the summer and fall of 2004. A wider area will be surveyed and new sampling techniques will be tested.

In the July-September, 2003 reporting period, as well as the October-December, 2003 period, the geochemical sampling program was extended with surveys conducted over three field sites in Michigan: Bear Lake, Springdale and Charlton 6 (Figure 1).

The protocols for the geochemical sampling program have now been established. All site locations are recorded using GPS receivers and duplicate samples are being stored at Michigan Tech. In the future, sampling will focus on using activated charcoal to trap soil gases followed by analysis by gas chromatograph. It appears that a technique that uses a known baseline is best since natural samples contain multiple gases that are difficult to interpret.

The results of the Bear Lake, Vernon, Springdale, and North Dakota geochemical surveys can be applied to other carbonate reservoirs worldwide. In particular, the application of appropriate surface geochemistry surveys seems warranted based on the work done here, as well as the advice to record the surveys at the same grid density as complimentary seismic data. The shallow-shelf and reef carbonates in the Permian Basin, the mid-continent, and Rocky Mountains (e.g. Williston basin) are logical targets for application of these techniques.

Did Data Support Project or Not?

The surface geochemistry data did support the demonstration projects quite well: it predicted that the demonstration wells would likely encounter or not encounter hydrocarbons. In other words, the geochemistry showed strong anomalies (Bear Lake, Springdale and Myrtle Beach) that would justify drilling on the basis of that data alone and even more so in conjunction with the seismic and subsurface well data.

Future Work

More geochemical work will be done in conjunction with further field demonstrations as part of this project in Michigan. New demonstration wells are planned for Michigan to test the Silurian reef play in another area. Preliminary results using both the Site Specific Micro Extraction (SPME) and the microbial techniques show good anomaly patterns for the Silurian Niagaran reefs. Activated carbon appears to hold good potential for detecting hydrocarbon anomalies and will be further evaluated in one or more demonstration areas.

Technology Transfer

A booth was set up at the Midwest PTTC horizontal well conference in Mt. Pleasant, MI in March, 2003 to show operators in the Basin the results of geochemical surveys in the basin. A technical paper on well log tomography was published in the April 2003 issue of the Bulletin of the American Association of Petroleum Geologists. A booth was set up with computer hardware at the Eastern Section Meeting of the American Association of Petroleum Geologist's in Pittsburgh, PA in September, 2003 to show live animations and visualizations of our regional mapping and geochemistry database to basin operators and technical personnel. A seminar was presented at Western Michigan University on well log tomography with examples from the Michigan Basin, including the regional fault interpretations in September, 2003. Computer demonstrations and discussions were held at the PTTC core workshop in Mt. Pleasant, MI in October, 2003.

An article on the Bear Lake geochemistry survey and successful horizontal re-entry was prepared for World Oil but was unable to be published due to confidentiality concerns of our industry partner. We plan to publish this article in the future.

An invited presentation was made at the U. S. Geological Survey in Reston, VA in December, 2003 on our regional mapping and fault delineation work. An article was published in the February 9, 2004 issue of the Oil and Gas Journal that highlighted our regional sample attribute mapping and fault delineation work. The annual planning meeting for our industry partners was held in Tampa, FL in early March 2004. Regional maps were posted for viewing by operators from the basin at the PTTC core workshop on March 19, 2004 in Mt. Pleasant, MI. Regional maps were also posted in a booth at the Michigan Oil and Gas Association's Annual Oil Conference on April 22, 2004 in Gaylord, MI and an oral presentation was made highlighting opportunities for exploration in the Michigan Basin. We participated at the Michigan Geological Society Annual Field Excursion from April 30 to May 2 with a presentation on our basin-scale mapping and by attend-

ing several of the field stops in the Traverse and Dundee carbonates. Presentations were also made at the monthly northern SPE meeting in April, 2004 and at the monthly, MBGS meeting in May, 2004.

Results and presentations from a portion of this technology transfer are available on the internet at <http://www.geo.mtu.edu/~aswylie/indxhtml.htm> while our main subsurface visualization web page (<http://www.geo.mtu.edu/svl/>) is being updated and expanded.

2.0 EXPERIMENTAL

The theory behind surface geochemical exploration is that direct hydrocarbon indicators leaking from a subsurface petroleum reservoir can be measured on the surface by geochemical methods. Surface geochemistry has been successfully used as an exploration technique for over 50 years. According to the American Petroleum Institute, new field wildcat success rates in the U.S. over the last 50 years peaked in 1979 with a success rate of 19%, however, wildcat drilling programs based upon surface geochemistry have regularly produced success rates over 50% (Davidson, 1994). Surface geochemistry has had many opponents over the years. The refusal of geologists to accept theories of vertical migration has drastically impeded the serious funding of research, and in turn widespread acceptance of surface geochemical exploration (Davidson, 1994). Smith and Ellis (1963) questioned the basis for surface geochemistry by claiming that ethane and heavier hydrocarbons could have grasses and other vegetation as their source, making surface geochemical methods useless. Horvitz (1972) conclusively demonstrated the error in Smith and Ellis' technique, and that organic matter, grass, and roots in the soil do not produce significant amounts of soil hydrocarbons, especially in the ethane through hexane range. This reveals that significant concentrations of hydrocarbons in the soil must have originated not from near surface organics, but from a much deeper source.

There are several different types of anomalies that stem from hydrocarbon seepage, both micro-seepage and macroseepage. The usual shapes include apical or focal anomalies, halo or doughnut shaped anomalies, and linear or straight-line anomalies. Direct hydrocarbon indicator techniques such as the SPME method can yield any shape of anomaly, but microbial techniques always yield focal anomalies (Kartsev et al., 1959; Price, 1986).

2.1 Sampling Program

Throughout this project, the field locations were sampled with both the soil gas technique that is being tested with this study, and in one or more locales the Geo-Microbial Technologies' MOST microbial method to compare and contrast against the SPME technique. These techniques have slightly different sampling methodology. Boleneus (1994) suggested that at least six samples need to be taken within the anomaly's vicinity to confirm the anomaly. In order to accurately delineate anomalies associated with Niagaran pinnacle reefs, which have a relatively small areal extent, a sampling grid spacing of 200 meters was chosen.

2.2 Sample collection

Microbial samples were taken according to the instructions of Geo-Microbial Technologies (Ochelata, Oklahoma). These soil samples were taken with a shovel at an average depth of 8 inches and placed into paper bags with roll-down tops that were provided by GMT. The samples consisted of approximately 4 ounces of soil. Immediately after collection the samples were shipped overnight to GMT for analysis of butane-consuming microbes.

SPME Samples were taken at approximately 1-meter depth using a cordless power drill with a 1-inch auger bit to drill down 1 meter. A core was then manually taken using a soil-coring tool with a 4-foot handle. The sample core was then quickly placed into 125 ml glass sample jars with a

septum in the lid and sealed. The sample jars were filled to the point that there was just enough room for the SPME fiber to fit in the headspace during extraction, approximately 2/3 full.

In the Vernon demonstration area, surface iodine, enzyme leach selective extraction, and sorbed soil gas samples were also collected for geochemical analyses. Surface iodine samples were collected from the top one inch of the A-horizon. Enzyme leach selective extraction samples were collected just below the top of the B-horizon. Sorbed soil gas samples were collected from approximately one-meter depth, placed into a metal collection can along with biocide.

The sampling technique for the activated carbon method consists of burying small granules and/or fibers of activated charcoal (~24-30 inches), then retrieving them after 15-20 days. Samples were taken in the Bear Lake area in Manistee County, Michigan and at the Bagley prospect area in Ogemaw County.

2.3 Analytical Procedures

2.3.1 Solid-phase microextraction (SPME)

The soil samples were kept on ice during transportation from the field to the laboratory to reduce the amount of microbial activity within the sample jars. The samples were then brought up to room temperature prior to analysis. The samples were manually shaken very briefly to break up the soil and laid on their side for SPME extraction. The septum on the sample jars was too thick for the blunt SPME needle to puncture without bending and destroying the fiber, so the septum was first pierced with a sharp syringe needle. The analyst then pushed the SPME needle past the septum that seals the sample vial and depressed the plunger, exposing the fiber to the headspace above the sample. The hydrocarbon analytes adsorbed to the coating on the fiber. After 10 minutes of exposure to the headspace gas the fiber is drawn back into the hollow needle, and the needle is removed from the sample vial. Finally, the needle is inserted through the septum in the gas chromatograph injector port. The adsorbed analytes are then thermally desorbed and brought to the gas chromatograph column via the carrier gas.

SPME Analytical Equipment

Analyses were carried out with a SRI 8610c gas chromatograph (GC) equipped with a flame ionization detector (FID) and hydrogen as carrier gas. Air for the FID combustion was supplied via a built-in air compressor on the 8610c. A Varian Chrompack CP7348, 25m long x 0.25mm in diameter, with a Porabond Q fused silica capillary column was used as the stationary phase. Samples were injected via the SPME sampler into a heated injection port held at 250 C. The standard injection port liner was replaced with a narrow bore (0.75mm) injection port sleeve to sharpen the peaks from the SPME techniques. The column oven was programmed to begin holding at 30 C for 5 minutes and then ramp at a rate of 10 C/min until it reached 200 C and was held there for an additional 5 minutes. Analyses were performed in the laboratory to a large extent and in the field to a small extent in order to determine the shelf life of the collected soil samples. In the laboratory the carrier and flame gas was supplied through compressed gas in tanks, in the field, the gas chromatograph was set up in the hotel with a SRI hydrogen generator producing the gas. Data acquisition and analysis were done with SRI's PeakSimple software.

SPME Calibration of Equipment

The laboratory equipment was calibrated using a standardized gas mixture of methane, ethane, propane, N-butane, N-pentane, and N-hexane. In the test gas mixture, each gas was present at 1000 ppm by mole. The test gas mixture was analyzed several times with the SPME fiber to determine the retention time for each individual hydrocarbon gas. The analyte adsorption and desorption was then varied to determine the optimum analysis procedures. The temperature program for the gas chromatograph's column oven also needed to be optimized for both speed of analysis and separation of the analytes in question. The test gas was then mixed with air to make mixtures of gases with analyte concentrations less than 1000 ppm. Mixtures with several different concentrations were analyzed with the gas chromatograph to calibrate the instrument so that retention areas could be converted to concentrations in parts per million. The retention areas turned out to be roughly linearly proportional to ppm concentrations. In this project, the actual concentration of hydrocarbons measured is not significant, but the proportion of one to another is very significant. When retention areas are converted over to ppm concentrations, some interpolation is required. In this study, to keep analytical error to a minimum, retention areas are used in the place of concentrations to compare one sample to another.

2.3.2 MOST

After receiving the soil samples, Geo-Microbial Technologies incubates the soil samples for one week in agar gel. Microorganisms tolerant to butanol are then selectively counted. The theory is that butane-consuming or butanol-resistant bacteria indicate hydrocarbon microseepage. As butane (and other hydrocarbons) migrates up through the soil, microorganisms will oxidize it, leaving butanol. In areas of high hydrocarbon seepage, the number of butanol resistant microbes is elevated. The number provided in GMT's laboratory report corresponds to the number of colonies of butane-oxidizing microbes that have grown in the laboratory on a Petri dish after seven days of incubation. Three separate dishes, or plates, are prepared for each soil sample; each is counted and the number reported is the average of the three plates (Schumacher, 2002).

2.3.3 Sorbed Soil gas

The sorbed soil gas method (Horvitz, 1985) involves acid extraction of light hydrocarbon gases that are sorbed onto clays or incorporated into carbonate cements in near-surface soils. The gases accumulate through microseepage from the hydrocarbon reservoir. Geo-Microbial Technologies, Inc. (GMT) determined the sorbed soil gases by flame ionization detector gas chromatography of the scrubbed and liberated gases. Soil samples were collected from approximately one-meter depth, placed into a metal collection can along with biocide (supplied by GMT). The concentration of light hydrocarbons can be used as an indicator of increased hydrocarbon microseepage. The ratios of the hydrocarbons, combined with published empirical soil gas ratios (Jones and Drozd, 1983) can be used to establish whether a prospect is in an oil, gas, or mixed prone region.

2.3.4 Surface Iodine

Iodine in surface soil samples has been demonstrated in the literature as an effective pathfinder for oil and gas in the subsurface (Gallagher, 1995). High concentrations of iodine are documented

elsewhere around the perimeter of subsurface oil and gas accumulations, "classic" halo anomaly, and directly above the accumulation, apical anomaly. The halo effect is interpreted as the surface expression of a reduction pipe above the oil and gas accumulation. Soil was collected from the top one inch of the A-horizon for surface iodine analysis. Data and interpretations for this survey are discussed in the geochemical conclusions.

2.3.5 Trace Element and Rare Earths - Enzyme Leach Selective Extraction

The enzyme leach selective extraction method is based on selective extraction of elements trapped on amorphous MnO₂ (Tompkins et al., 2000). Amorphous MnO₂ is a very effective trap for migrating cations, anions, and polar molecules. Oxidation anomalies are predicted over reduced bodies in the subsurface for a suite of elements including Cl, Br, I, As, Sb, Mo, W, Re, Se, Te, V, U, and Th (oxidation suite). Rare-earth elements often follow the same pattern as the oxidation suite. Base metals can be anomalous, but with lower contrast with the background. According to Clark, the most common form of oxidation anomalies is as a halo with a central low over the reduced body in the subsurface. These anomalies may be symmetric, asymmetric, or partial around the buried reduced bodies. Clark provides an electrochemical interpretation for halo oxidation anomalies. Apical anomalies are most often interpreted as related to faults. Since enzyme leach anomalies take 100's of years to develop, they will exist long after oil has been extracted from a reservoir. Soil samples for this technique are collected from just below the top of the B-horizon.

2.3.6 Activated Carbon

Activated charcoal samples were collected in the Bear Lake and Bagley prospect areas in Manistee and Ogemaw Counties, Michigan. This technique consists of burying small granules and/or fibers of activated charcoal (~24-30 inches), then retrieving them after 15-20 days and analyzing them in the Gas Chromatograph. This is a proven technique that has the advantage of looking at changes in a known sample and relating them directly to the sample environment. The disadvantage is that the samples have to be retrieved, necessitating two trips to the site. However, given the problems inherent in sampling material from the site itself, this technique seems to offer the most promise, both in terms of reliability and accuracy. It will be further tested, using substrates other than activate charcoal, over a variety of sites.

2.4 Geochemistry Sample Collection – Michigan and North Dakota

All geochemical data collected to date (1100+ samples) has been archived in a MS Access database. This database will be placed online along with interpretive text in the future.

2.5 Geochemistry Program in Springdale Area, Manistee County, Michigan

A surface geochemistry program was undertaken in the Springdale area, Manistee County, Michigan to determine if geochemical anomalies could discern the limits of the newly discovered Niagaran reservoir (Figures 1 and 5). The survey was designed to examine the microbial geochemical technique using activated charcoal as the collection media.

2.6 Geochemistry Program in Bear Lake Area, Manistee County, Michigan

A surface geochemistry program was undertaken in the Bear Lake area in order to discover if geochemical anomalies were associated with the Niagaran production in the area (Figure 1 shows the location of this survey relative to similar Class Revisit geochemical sampling programs in the basin; Figures 8 and 9 show the Bear Lake survey area and sample locations) (Seaman, 2003). The survey was designed to examine two different geochemical techniques: solid-phase microextraction (SPME) that measures the concentration of C1-C6 hydrocarbons in the headspace gas of near-surface soil, and microbial oil surveying technique (MOST) that measures the hydrocarbon gases or hydrocarbon indicators at the ground surface.

2.7 Geochemistry Program in Vernon Field Area, Isabella County, Michigan

A surface geochemistry program was initiated at Vernon Field in order to discover if geochemical anomalies were associated with the field. The surveys were designed to examine four different geochemical techniques based on a literature review and discussions with vendors. The four geochemical techniques to be evaluated were: surface iodine, microbial, enzyme leach, and soil-gas. These are established techniques with a supportive literature and a number of service companies willing to conduct the surveys and/or do the analyses. In this study, project personnel collected all samples and interpreted the data. Commercial service companies conducted the analyses.

2.8 Geochemistry Program in Myrtle Beach Area, Burke County, North Dakota

A surface geochemistry program was initiated in the Myrtle Beach Prospect area in Burke County, North Dakota, taking samples for microbial. It is apparent from the elevated microbial values that we need to go back and sample a larger area to try to obtain samples with lower microbial values off the prospect. In this area, project personnel collected all samples and interpreted the data.

2.9 Subsurface Mapping of Dundee and Rogers City Limestones, Michigan

More than 900 digital well logs within the Lower Peninsula were reviewed from the Spatial Subsurface Visualization Laboratory database at MTU. The final 295 wells used for well log tomography were selected based upon two primary criteria. Most importantly, the wells had to contain a gamma ray curve throughout the entire Dundee and Rogers City interval. Incomplete or missing gamma ray curves accounted for twenty percent of those wells needing to be discarded. Secondly, groupings of wells within close proximity to one another were eliminated in order to obtain a uniform distribution over the basin. For example, after reviewing each well from an oil field or cluster within a county, only one or two representative wells were chosen instead of keeping every well that met the first criterion. This eliminated seventy-five percent of the LAS files. The remaining five percent of excluded LAS files were removed based on duplicate or triplicate files, deviated well, digitizing errors, outliers, or wells that appeared questionable. Roughly half the selected wells also have bulk density and photoelectric effect curves. Formation tops for the 295

wells were then picked including the Rogers City, Dundee, Detroit River and Detroit River Bentonite to use as chronostratigraphic surfaces for the various slicing techniques.

3.0 RESULTS AND DISCUSSION

3.1 Summary - Springdale Area - Manistee County, Michigan

Analysis of the geology of the Springdale prospect will continue following the successful wells there. The focus will be on collecting additional geochemical data and identifying the controls on this play and the role of surface geochemistry. We hope to produce a detailed geological model for this field and integrate the geochemical data into it. Additional microbial data will be collected in 2004 over an expanded area in sections 15, 16, 21 and 22 (refer to Figure 5).

3.2 Summary - Bear Lake Area - Manistee County, Michigan

Federated Oil and Gas re-entered the Charlich-Fauble well in Section 9 and drilled a horizontal lateral approximately 550 feet toward the southwest after the geochemical survey had been recorded. The target reservoir was a Niagaran reef that had been delineated using seismic and sub-surface data without input or knowledge of the results of the geochemical survey. The solid phase microextraction geochemical survey results indicate anomalies in the vicinity of the path of this lateral well. The well was successful and is flowing oil from the target Niagaran reef at the rate of 75 to 100 barrels of oil per day 15 months after the initial recompletion; the recompleted well has made more than 62,000 barrels of oil. We will monitor the positive results from this well in subsequent quarters. (Figure 9, Refer to Technical Quarterly Reports #15122R14, January-March 2003 and #15122R17, July-September 2003).

3.3 Summary - Vernon Area - Isabella County, Michigan

The major findings are that the large-scale survey at Vernon Field, conducted early on in this project, appears now to be best interpreted as a halo anomaly over a depleted field (Figure 7, refer to Technical Quarterly Report #15122R13, October-December 2002).

3.4 Summary - Myrtle Beach Area, Burke County, North Dakota

A surface geochemistry program in the Myrtle Beach Prospect area in Burke County, North Dakota, collected more than 40 samples for microbial analysis (Figure 11). The microbial results from the 40+ samples were extremely high; higher than any microbial analysis from our Michigan data set.

Well details for the Lawrence 10-21 and Holte 6-21 wells were presented in the Quarterly Technical Report for period ending June 30, 2003 (refer to Technical Annual Report #15122R16, April-June 2003). Negotiations are continuing by our industry partner in a effort to reach agreement on constructing a pipeline to these wells so they may go on production.

3.5 Dundee and Rogers City - Regional Facies Tract Mapping

Gamma ray, bulk density and photoelectric effect log curves for the Dundee and Rogers City Limestones were digitized from vertical wells distributed over the Lower Peninsula of Michigan, converted to Log ASCII Standard files, and input into the well log tomography program. The "slicing" contour results indicate that during the formation of the Dundee and Rogers City Limestone units, carbonates and evaporites with low natural radioactive signatures on gamma ray logs were deposited and clastic input was minimal to non-existent. A subtle north-south, low natural radioactive trend in the center of the basin correlates with a similar Pef trend and these trends may correlate with previously published Dundee facies tracts. High bulk density trends in the western Michigan Basin correlate with the limits of the Reed City Member (anhydrite) of the Dundee.

3.5.1 Stratigraphy

Detroit River Group

The upper Detroit River Group directly underlies the Dundee Limestone (Figures 13) and is composed of a cyclic series of shallow-water dolomite, limestone, sandstone, anhydrite and salt units (Lilienthal, 1978). In the Lower Peninsula, the Detroit River Group is present except in the extreme northern and southeastern regions. The contact between the Detroit River Group and the Dundee Limestone is irregularly marked by an erosional unconformity and is difficult to distinguish in the subsurface due to similarity in lithologies and hence well log responses on either side of the contact (Landes, 1951; Baltrusaitis, 1974). Lilienthal (1978) stated that the top Detroit River pick is often placed a few feet below the top of the Detroit River Group at the first anhydrite or is based upon other lithology characteristics when this anhydrite is not present. Gardner (1974) was one of the workers that used the anhydrite to define the contact except in the absence of anhydrite toward the southeast region of the basin, where he instead used a thin potassium-bentonite ash bed as described below.

Kawkawlin Bentonite

The uppermost unit of the Detroit River Group contains a volcanic bentonite ash bed (Figure 13). Baltrusaitis (1974) proposed the name Kawkawlin Bentonite for this chronostratigraphic surface after the type well located in the Kawkawlin oil field, Bay County, Michigan. This bentonite can be regionally correlated to the Tioga Bentonite of southwestern Ontario (Baltrusaitis, 1974) and northern Indiana (Doheny et al., 1975). As shown in Figure 15, the ash-fall bed appears as a "spike" on gamma ray logs. Baltrusaitis (1974) also identified a second ash bed above the Kawkawlin Bentonite, possessing a similar gamma ray signature but having a slightly different composition. This additional bentonite spike is not present in the well shown in Figure 15 but can be observed in other gamma ray log curves throughout the basin.

Dundee Limestone

The Dundee Limestone is present throughout most of the Lower Peninsula. The formation outcrops in the northernmost counties, subcrops beneath the glacial drift in southeastern Michigan

and is absent due to erosion in the southwest Lower Peninsula (Figure 14). The Dundee Limestone is described as a "buff-to-brownish gray, finely to coarsely crystalline limestone" (Lilienthal, 1978; Catacosinos et al., 1991). In the westernmost regions of the basin, the Dundee is typically dolomite whereas both limestone and dolomite are present in the basin center. Primary and secondary porosity zones within the limestone and dolomite play a significant role in Dundee oil and gas production (Lilienthal, 1978).

The contact between the Dundee Limestone and the overlying Rogers City was originally described as conformable (Ehlers and Radabaugh, 1938; Tinklepaugh, 1957). Radabaugh (1942) made a detailed map of the northern Rogers City outcrop and showed that the limestone thinned from north to south across the basin but could not confirm if the absence of the Rogers City was due to erosion or non-deposition. A more recent publication by Curran and Hurley (1992), in their study of the West Branch oil field in Ogemaw County, stated that this contact is a disconformity, distinguished by a pyritized and bored hardground due to a period of non-deposition coincident with the top of the Dundee.

Reed City Member

The Reed City is a Member within the Dundee Limestone and is only present in the westernmost Michigan Basin (Figure 13) and consequently could not be used as a regionally correlative surface for slicing. Gardner (1974) described the Reed City as a porosity zone containing both laminated anhydrite and massive dolomite deposited during a brief period of Dundee sea regression. This porosity zone is important because it produces both oil and gas (Lilienthal, 1978) and helps define the Dundee depositional environment.

Rogers City Limestone

The initial separation of the Rogers City Limestone from the Dundee Limestone was based on quarry exposures at Rogers City in Presque Isle County in the northeastern lower peninsula (Ehlers and Radabaugh, 1938). Shortly after this initial publication, Addison (1940) described the Rogers City based on subsurface lithology data at Buckeye oil field in Gladwin County. Addison noted that the Rogers City was darker and denser than the Dundee. Similarly, Landes (1944) described the Rogers City to be "waxy" and darker than the Dundee at Porter oil field in Midland County. Within this oil field, distinguishing between the Rogers City and the Dundee had economic importance as oil was produced directly beneath the Dundee-Rogers City contact (Landes, 1944). The Rogers City-Dundee contact is difficult to consistently pick in the subsurface using geophysical log curves due to the similarity in lithology above and below the contact and also because the Rogers City progressively thins and is eroded or laps out in the southern third of the lower peninsula.

The contact between the Rogers City and the overlying Bell Shale is readily apparent in the subsurface on gamma ray, bulk density and pef log curves. This contact was originally described as a disconformity (Ehlers and Radabaugh, 1938) based on removal of 46 feet of Rogers City Limestone at Michigan Limestone and Chemical Company quarry in Presque Isle County. Other workers such as Radabaugh (1942) and Ehlers and Kesling (1970) confirmed this disconformity, but based their interpretations upon data from the margins of the Michigan basin. Addison (1940)

stated that the thickness of the Rogers City did not vary over an anticlinal structure in the Buckeye field of central Michigan. From this observation Addison concluded that the contact between the Bell Shale and the Rogers City appeared to be conformable. Gardner (1974) concluded that an unconformable relationship exists between the Rogers City and the Bell Shale at the basin margin but is conformable in the deeper, central region of the basin.

Bell Shale

The Bell Shale is the basal formation of the Traverse Group and directly overlies the Rogers City Limestone. When the Rogers City is not present, in areas such as western and southern Michigan, the Bell Shale overlies the Dundee Limestone. In 1901, Amadeus W. Grabau first used the term "Bell Shale" when describing bluish colored shale in abandoned clay pits in southeastern Presque Isle County (Ehlers and Kesling, 1970). The Bell Shale Formation studied at quarries and from cores in Presque Isle and Alpena Counties, was deposited on an erosional surface at the top of the Rogers City Limestone.

The lower section of the Bell Shale contains crinoid fragments indicating turbulent water conditions whereas fossils in the upper section depict a calmer, deep-water environment (Ehlers and Kesling, 1970). Bloomer (1969) described a small calcareous unit (lag deposit) at the base of the Bell Shale in the southwest region of the Michigan basin and interpreted the lag to be time transgressive toward the northeast as the result of transgression.

3.5.2 Well Log Tomography - Gamma Ray, Bulk Density and Photoelectric Effect Curves

The well log tomography (WLT) method employs wireline logs. Wireline tools can record and sample geophysical measurements at one-foot intervals or higher resolutions within a borehole. However, as described by Wylie (2002), common practice is to average wireline log curve amplitudes over the interval under analysis when correlating well data. Consequently, Wylie's primary objective for creating the slicing program (WLT) was to analyze well log curves without compromising their vertical resolution (Wylie, 2002; Wylie and Huntoon, 2003). By creating a slice at every foot, the full vertical resolution contained within the log curve data is preserved in each well. The log curve amplitudes for each well are then plotted and contoured in plan-view. In this study we use the gamma ray, bulk density (ρ_{b}) and photoelectric effect (P_{ef}) log curves to analyze regional variations in the Dundee and Rogers City Limestones.

Gamma Ray Curve

The gamma ray curve records the natural radioactivity of a formation due to the presence of three radioisotopes, uranium (^{238}U), potassium (^{40}K) and thorium (^{232}Th). As the isotopes of U, K and Th decay, they emit short bursts of electromagnetic energy that can be measured by a gamma ray sensor. The American Petroleum Institute unit (API) is used as a measurement for gamma ray logs and is based on an artificial formation located in Houston, TX containing known values of U, K and Th. A basic gamma ray log records the combined energies from U, K and Th whereas a spectral gamma ray log separates the signal into its three components.

Gamma ray logs are useful for lithology studies because different types of sedimentary rocks exhibit a general range of gamma ray responses. Dewan (1983) stated that generally, pure limestone and anhydrite measure 15-20 API, dolomite and sandstones range between 20-30 API, and shales and volcanic ash (potassium-bentonite) measure high, on average 100 API. In the Dundee and Rogers City formations, anhydrite primarily ranges from 10-14 API, limestone averages 16 API and dolomite covers a broad range, between 10-50 API. The Bell Shale averages approximately 120 API.

Bulk Density Curve

Density logs are used primarily to measure formation porosity but they can also be used to identify evaporite minerals (i.e., the Reed City Member of the Dundee). Density tools work by emitting gamma rays and then these gamma rays collide with electrons of the formation under analysis. Each collision causes any gamma ray to lose some but not all of its energy to the electron and the gamma ray continues with diminished energy and reaches a detector in the bulk density logging tool, at a fixed distance from the source, where it is counted as an indication of formation density. The response of the density tool is related to the electron density of the formation, which is related to bulk density. The density of the rock is a function of its matrix, fluid content, and pore space (Schlumberger, 1986). This study applied WLT to a 150 well subset of the well logs used for the gamma ray mapping that had ρ_{b} curves to map basin-scale variations in the bulk density as an indicator of lithology and especially evaporites in the Dundee.

Photoelectric Absorption Curve

Photoelectric absorption measures how many gamma rays reach a low energy level after being scattered by the electrons in the formation (Columbia, 2004). The photoelectric effect index is measured by comparing the counts from a far detector in the high energy region, with those counts in the low energy region, where the count rates depend on both the reactions. The far detector is used because it has a greater depth of investigation. The photoelectric absorption cross section index is measured downhole and is related to the atomic number of the formation and hence to the lithology making the Pef curve a separate indicator of formation lithology. This study applied WLT to approximately 150 wells at the basin-scale to map lithology variations using the Pef curve in the Dundee and Rogers City for comparison with the gamma ray and bulk density WLT mapping.

Borehole Correction

Borehole effects are important to note in this study as they can affect the gamma ray response. Conditions for calibration of the gamma ray tool are defined by Dewan (1983) to include a hole diameter of 8-in, 10-lb drilling mud, and an eccentric logging tool with a 3 5/8-in diameter. A dampened gamma ray response can be attributed to an increase in either the hole diameter or mud weight, or with the use of a centralized logging tool. Conversely, a smaller hole would shift the log curve toward higher gamma ray values (Dewan, 1983).

Charts such as the Schlumberger Por-7, provide correction factors that account for borehole effects using the hole diameter, mud weight and tool position (Schlumberger, 1986). Although the

mud weight was typically recorded in the LAS files and in the header of the original paper logs, neither the hole diameter nor tool position were available in the LAS files or on the paper logs. Consequently, a typical borehole correction could not be performed and is noted as a source of error in the data set.

Casing sizes, ranging from 4 1/2-in to 13 5/8-in, for 217 wells within the "Dundee" interval were available. By mapping the distribution of gamma ray and casing size values for individual wells within the basin, there appeared to be no direct correlation between the casing size and the gamma ray amplitude. The casing sizes were then used as a proxy for borehole diameter and plotted against the gamma ray response for each well to observe possible relationships that could aid in applying a borehole correction. Two cross-plots were used to determine the necessity for a borehole correction: (A) the average gamma ray value for the "Dundee" interval in each well plotted as a function of casing diameter and (B) standard deviation of the gamma ray values for the "Dundee" interval in each well plotted as a function of casing diameter. From these graphs, there is no apparent relationship between the casing size and the gamma ray values. A trend was observed between the distribution of small casing sizes and the standard deviation of the gamma ray values for each well. However, the cause of this relationship in the center of the basin, but not consistently over the entire basin, is unknown.

Normalization

Neinast and Knox (1974) and Hunt et al (1996) stated that more than half of wells studied need to be normalized. Normalization is a correction applied to erroneous well log data to ensure that there is consistency between wells regarding the amplitude of the log curve response. The WLT technique examines amplitude changes rather than absolute amplitude values, but normalization was investigated because different types of errors can alter the amplitude change. "The basic sources of error are tool malfunction, incorrect tool design, inconsistent shop and field calibration, and operator error" (Neinast and Knox, 1974). In addition to these sources, Shier (1997) showed significant variation in gamma ray responses based on a combination of logging contractors, drilling medium, and tool vintages. Hammack and Fertl (1974) described subsurface conditions that cause increased gamma ray amplitudes such as previously perforated intervals with salt present from old drilling fluid, fluid movement behind casing, and the presence of radioactive sandstones and carbonates. Hammack and Fertl also stated that "interpretation of gamma ray logs is straightforward if correctly calibrated and proper time constant and logging speed are used," although, these log constraints are typically unknown for well logs within the Michigan Basin.

The normalization process includes defining a standard curve signature from either one well or a combination of representative wells. This "standard" can be based on a unit of sufficient lateral extent such as a shale layer, a low porosity carbonate or thick sandstone with low porosity. Each well used in the study is then normalized with the standard (Hunt et al., 1996). In this study, a standard formation either above or below the Dundee-Rogers City interval was difficult to identify because of lithology changes across the basin and incomplete digital gamma ray log curve coverage. The Dundee-Rogers City interval was then analyzed to determine if it had a unique log curve signature that could be used as the standard to correct erroneous log amplitudes. This analysis consisted of creating frequency histograms of the gamma ray values within the Dundee-Rogers City interval for individual wells throughout the basin. Consequently, normalization using one

standard for the entire basin could not be performed because the correction was beyond the scope of this study and is noted as a source of error.

As a broad normalization for the 302 wells that were preliminarily sliced, a composite frequency histogram was constructed using the average gamma ray value for the Dundee-Rogers City interval in each well. Of the 302 wells, all but seven wells fell within two standard deviations that equal about 95 percent of the data. Four wells were within the third standard deviation (99.7 percent of data) and three wells were far beyond the mean value. All seven wells were further analyzed and excluded from the final slicing.

Formation Tops Data

The WLT technique slices log curve data between two correlative surfaces. Wylie and Huntoon (2003) stated that if these bounding surfaces can be defined as unconformities, sequence boundaries, parasequence boundaries, flooding surfaces, condensed sections or ash beds, then the slicing image results would be chronostratigraphically significant. An example of a chronostratigraphic surface would be the images that a satellite captures of the modern depositional surface.

Originally, the Dundee and Rogers City Limestones were not separated in this study because the location of their contact, based on previous publications, could not be identified with a high level of certainty using gamma ray logs. The top of the combined "Dundee" limestone was picked at the inflection point on the gamma ray log curve between the Bell Shale and the "Dundee" for every well (Figure 15). The inflection point was chosen as the contact because the complete change from shale to limestone on the logs was typically within the 3-4 ft vertical resolution range for the gamma ray data (Dewan, 1983). In general, the top of the "Dundee" was easier to identify in the center of the basin than in the southwest where the Bell Shale unit pinches or laps out. Most of these picks are equivalent to the top values within the Michigan Department of Environmental Quality Oil and Gas Database (DNR).

The base of the "Dundee" was defined at the first anhydrite within the Detroit River Group. This pick was most consistently picked when the density log curve was available (Figure 15) and became more difficult to pick in the southeastern part of the basin where log signatures for both units become exceedingly similar. These top picks were fairly consistent with the DNR database.

The top boundary of the "Dundee" is marked by an abrupt lithology change as well as an unconformity at the basin margins (Gardner, 1974). This correlative surface may be chronostratigraphically significant although Bloomer (1969) stated that, "the Dundee [including Rogers City] is not time equivalent" due to varying rates of deposition, such that increased distance from this surface would decrease the time significance of a given slice. Similarly, slices from the base of the "Dundee" only illustrate approximate time surfaces.

3.5.3 Depositional Model

The Michigan Basin's paleogeography during Dundee-Rogers City time (376-380 Ma) was approximately 20°S and modeling of the tropical paleoclimate illustrates that the mean tempera-

ture would have averaged 75° Fahrenheit (24° Celsius) (Golonka et al., 1994). Gardner (1974) presented a comprehensive interpretation for this Middle Devonian depositional environment using well cuttings, cores, driller's logs and gamma ray-neutron wireline log curves. In his conceptual model, the basin was divided into three zones, where sediments in the western region of the basin indicate a sabkha-lagoon environment, separated from an eastern open marine environment by a north-south trending shell bank (Figure 17B). A westward transgressing sea and an intermediate regression during Reed City deposition controlled this environmental differentiation (Gardner, 1974).

Many workers applied the Rogers City-Dundee depositional model proposed by Gardner (1974) to their own studies (Lilienthal, 1978; Bush, 1983; Fisher et al., 1988; Catacosinos et al., 1991; Howell and van der Pluijm, 1999). Prior to Gardner's (1974) division of the Michigan Basin, Cohee and Underwood (1945) illustrated a similar north-south separation based on Dundee and Rogers City oil production. Wells west of Gladwin and Midland counties produced primarily from the Rogers City whereas, wells east of this divide produced primarily from the Dundee. Montgomery (1986) and Curran and Hurley (1992) separated the Rogers City and Dundee depositional environments in the center of the basin. The Rogers City Limestone was described as open-marine, and the Dundee Limestone as composed of mostly patch reefs (Montgomery, 1986) in a shallow platform environment (Curran and Hurley, 1992).

The most recent interpretation of the middle to late Dundee depositional environment was presented by Taylor (2001) and closely resembles Gardner's model (Figure 17B). Taylor used a high density of well log curves (more than 1500 well logs) to separate the sabkha from the lagoon environment and identify smaller scale features such as tidal channels, barrier islands and patch reefs. The drawback to typical models such as those shown in Figure 17B is that they only provide one generalized representation of the depositional environment whereas the WLT technique attempts to depict the evolution of depositional patterns.

A subtle similarity exists between the depositional environment proposed by both Gardner (1974) and Taylor (2001) and the trends observed in the proportional slicing shown in Figure 16 as well as in the top-down and bottom-up slicing that is not shown. The location of the shell banks (Gardner, 1974) and inner shelf region (Taylor, 2001) appears as a low gamma ray trend running north-south through the center of the basin in slices through the mid- and upper-Dundee and to a lesser extent through the slice of the Rogers City (dark blues, left most slices, Figure 13). The photoelectric effect slices (right most slices, Figure 13) show similar north-south trends and indicate that the shell banks or inner shelf region is predominantly composed of dolomite. The gamma ray slices also illustrate a consistently higher naturally radioactive region in the southeast basin, described by previous workers as a shallow marine environment area (Gardner, 1974; Taylor, 2001).

Figure 17 superimposes Taylor's (2001) map onto slice 19 from the top-down slicing (upper Dundee). An interpretation of this figure suggests that beyond Taylor's study region, the low natural radioactive trend appears to expand in the northern part of the basin. The occurrence of low naturally radioactive sediments could be attributed to reworking of carbonate material through wave action. The high bulk density (ρ_{b}) amplitudes in the slices (oranges and yellows in the middle column of slices in Figure 13) clearly show that evaporite (anhydrite, Reed City Member) deposition dominated in the western one third of the Michigan basin during lower to upper

Dundee time. Comparison of the gamma ray, bulk density, evaporites and carbonates that can be observed regionally using the gamma ray, bulk density and pef log curves.

In a publication on the identification of depositional environments using gamma ray logs, Rider (1990) stated that too many complications and variations exist to base interpretations solely on one log curve. This is evident in slicing the Dundee and Rogers City Limestones as the gamma ray curve does not identify all lithofacies changes. Lilienthal (1978) stated that porosity zones could be traced in the Dundee-Rogers City interval across the basin using the neutron log. Applying WLT to the neutron curve could highlight important porosity trends. The density log was useful for identifying anhydrite and slicing this curve allowed the delineation of the extent of the Reed City Member. If digital lithology or facies data could be assigned amplitude values and input into the WLT slicing program, the resulting trends could improve both the Rogers City and Dundee depositional environment models.

4.0 CONCLUSIONS

The positive results from the Springdale wells show that hydrocarbons can still be recovered in the Michigan Basin by small companies. We now need to establish the reserves and see if there are any further plays in the area. This work will likely stretch out over at least two years, but it is likely that much can be accomplished this summer, year 4 of this project. Thus, we should have a good case history to write up for the final report. In addition, the Springdale play will be presented at various meetings and symposia, including PTTC workshops in the coming years. The main questions now are: 1. the size of the reserves, 2. the presence of additional fields nearby, and 3. details of the geology, including the type of trap and how to locate them. More data will be collected in an expanded area at Springdale in 2004.

Microbial sampling over the Bear Lake prospect has considerably widened the original microbial and SPME coverage there. It appears that the discovery well is now producing a negative (halo) anomaly due to the pressure draw-down and this is reflected in the microbial data. However several relative highs were picked up in the new survey that bear further investigation, preferably by 2d seismic lines to see if there is any structure associated with them.

In general, the geochemical program is proving a valuable addition to the demonstration program in this project. We have mapped both positive and negative anomalies over the demonstration sites and have been able to correlate these observations with production. In general the negative anomalies correlate with produced fields or with reefs that are currently pumping. Positive anomalies occur over prospects that have not been drilled and where at least shows of hydrocarbons were encountered in the subsequent tests. The extensive geochemical sampling over Vernon Field is now seen in retrospect to have defined a large negative anomaly associated with the entire field, indicating that it was a poor candidate for further development, a result confirmed by the drilling of the Smock 13-23-HD1 test well.

We have also developed a sampling and analysis protocol for surface geochemistry based on retrieval of activated carbon and analysis by gas chromatography. This technique is still being developed, but side-by-side comparisons with the microbial data can be used to compare the efficiency and accuracy (consistency) of the technique. If the activated carbon technique proves accurate, it has the advantage of being lower cost and more adaptable to routine application by small operators. We will emphasize this aspect of the project in our future reports.

The well log tomography technique was successfully applied to the Rogers City and Dundee Limestones in the Michigan Basin. The primary result from the suite of gamma ray, rhob and pef log curves sliced over the Lower Peninsula of Michigan indicated a period of quite carbonate and evaporite deposition occurred during Dundee-Rogers City time. This is in sharp contrast with the previous work on the overlying Traverse Group by Wylie (2002) and Wylie and Huntoon (2003) that identified multiple cycles of gamma ray distributions related to the expansion and contraction of muddy deltas in the eastern Michigan Basin. No comparable delta building activity is apparent in the gamma ray, rhob and pef data for the Dundee and Rogers City Limestones. A subtle north-south gamma ray and pef trend within the Dundee interval was found to correlate with previous interpretations of Dundee facies tracts by Gardner (1974) and Taylor (2001). In addition, the bulk density WLT images show the extent of the Reed City Evaporite Member of the Dundee Lime-

stone. By conducting more detailed mapping of the relationship of the Reed City Member and the north-south Dundee system tract, additional lead areas may be located in the Dundee for surface geochemical surveys.

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6.0 FIGURES

Figure 1. Index map showing locations of all geochemical sampling in Michigan and North Dakota.

Figure 2. Generalized Stratigraphic Column for the Michigan Basin.

ERA	PERIOD		ROCK UNIT
			FORMATION
Cenozoic	Quaternary		Oahe
			Brule
			Chadron
			Golden Valley
			Sentinel Butte
			Bullion Creek
			Slope
			Cannonball
			Ludlow
Mesozoic	Cretaceous		Hell Creek
			Fox Hills
			Pierre
			Niobrara
			Carlile
			Greenhorn
			Belle Fourche
			Mowry
			New Castle
			Skull Creek
			Inyan Kara
	Jurassic		Swift
			Rierdon
	Triassic		Piper
Paleozoic	Permian		Spearfish
			Minnekahta
			Opeche
			Broom Creek
	Carboniferous	Pennsylvanian	Amsden
			Tyler
			Otter
			Kibbey
			Charles
		Mississippian	Mission Canyon
			Lodgepole
			Bakken
	Devonian		Three Forks
			Birdbear
			Duperow
			Souris River
			Dawson Bay
			Prairie
			Winnipegosis
			Ashern
	Silurian		Interlake
			Stonewall
	Ordovician		Stony Mountain
			Red River
			Roughlock
			Icebox
			Black Island
	Cambrian		Deadwood
	PreCambrian		

Figure 3. Generalized Stratigraphic Column for the Williston Basin. Black dots are key productive intervals in the Myrtle Beach area.

Figure 4. Springdale area wells and surface geochemical sample locations. Red well path is St. Springdale & O'Driscoll 16-16 HD1 (Permit 55782). Large red circles are bottom hole locations (bhl) of horizontal wells; pink circles are bottom hole locations of deviated wells.

Figure 5. Microbial contour map of the Springdale Prospect in Manistee County, Michigan. Red well path is St. Springdale & O'Driscoll 16-16 HD1. Large red circles are bottom hole locations (bhl) of horizontal wells; pink circles are bottom hole locations of deviated wells. Green color filled contours indicate high microbial anomalies and yellow color filled contours indicate low anomalies. The change in the microbial anomaly along the path of the St. Springdale and O'Driscoll 16-16 HD1 may represent a fault or stratigraphic facies change.

Vernon Area, Isabella County, Michigan Microbial Contour Map		
Location: [T15-16N,R3-4W]	▲ Microbial Locations	C. Asiala
	✱ Gas Wells ✦ Oil Wells ◇ Dry Holes	MTU
	● Location Wells ✱ Brine Disposal Wells	6/15/2004

Figure 6. Microbial sample location map for the Vernon Field and surrounding area in Isabella County, Michigan. Black triangles are microbial sample locations and the dark gray symbols are well locations.

Vernon Area, Isabella County, Michigan Microbial Contour Map		
Location: [T15-16N,R3-4W]	▲ Microbial Locations	C. Asiala
Gridding Algorithm: Kriging	* Gas Wells ♦ Oil Wells ✧ Dry Holes	MTU
Contour Interval: 5	● Location Wells ✱ Brine Disposal Wells	6/15/2004

Figure 7. Microbial sample location map and contour map for the Vernon Field and surrounding area in Isabella County, Michigan. Black triangles are the microbial sample locations. Blue color filled contours indicate high microbial anomalies and yellow color filled contours indicate low anomalies. The entire Vernon Field is a large negative anomaly.

Figure 8. Microbial sample and well location map for the Bear Lake area, Manistee County, Michigan.

Figure 9. Microbial sample location and contour map for Bear Lake, Manistee County, Michigan. Blue contours indicate high microbial anomalies and yellow contours indicate low anomalies. Location of Charlich-Fauble sidetrack is shown by pink line.

Figure 10. Microbial sample locations in the Myrtle Beach area. Microbial counts posted in red below sample location. Black outline is location of 3D seismic survey. Blue lines are rivers and lakes, Green lines are roads, subsea Winnipegosis tops for 3 deep wells posted in red. North is toward top of map.

Figure 11. Microbial contour and sample locations in the Myrtle Beach area. Red and Purple color filled contours indicate high microbial anomalies and green indicates low anomalies. Contour interval is 5 microbial counts. The high microbial counts recorded here are the highest recorded in the project to date.

Figure 12. Location map for 2003 Dundee-Rogers City producing wells (black dots) from the Michigan Department of Natural Resources (MDNR) production database. County names are also shown for reference.

Figure 13. (A) Stratigraphy diagram for the Dundee-Rogers City and surrounding Middle Devonian units from west to east across the central Lower Peninsula of Michigan (modified from Catacosinos et al., 1991). (B) Cross-sectional stratigraphy schematic from southwest toward the center of the basin, illustrating that the Bell Shale, Rogers City and Dundee intervals are all absent in portions of southwestern Michigan. Note that the vertical scale is exaggerated.

Figure 14. Outcrop and subcrop locations for the Detroit River Group and the combined Dundee-Rogers City ("Dundee") unit. A dotted line in the southwest region illustrates the absence of the Dundee Limestone due to erosion. Black closed circles represent wells used in the WLT slicing program and orange open circles locate the wells discarded before slicing.

Figure 15. Example digital well log, from the Alber #1-23 well, permit 40215 located in Mecosta County, Michigan. The gamma ray (GR) log curve is located on the left track of the well log with a color-filled amplitude. On the right track are the density (RHOB) log curve (red), neutron (blue) and photoelectric effect (green). The top picks are labeled on the depth scale in the center track. The Reed City is labeled but has no top pick because it is only a Member of the Dundee and is not present throughout the entire basin. The horizontal lines are the location of the amplitude slices shown in Figure 16.

Figure 16. (Next Page) Comparison of four proportional gamma ray, bulk density (rhob) and photoelectric factor (Pef) slices for the Dundee and Rogers City Limestones in the Michigan Basin (refer to Figure 15 for approximate slice locations). Note the subtle North-South trends in the gamma ray and pef slices. The rhob slices show the extent of the Reed City Member (anhydrite). The gamma ray slice data range is 0 to 30 api units and the contour interval for each slice is 3 api units. The rhob slice data range is 2.0 to 3.0 grams per cubic centimeter (g/cc) and the contour interval is 0.07 g/cc. The data range for each Pef slice is 0 to 10 barns per electron (b/e). The contour interval is 0.6 b/e. 300 wells were used in the gamma ray slices, 150 wells were used in the rhob slicing and 121 wells were used in the Pef slicing. Gray lines are county boundaries and gray numbers are county names. North is toward the top of the slices. Large white dots are data control points on each slice. Yellow and black rectangles show the location of the Vernon geochemical survey area.

Figure 17. (A) Slice 19 from the top-down Dundee Limestone results. (B) Taylor's (2001) depositional model for the upper Dundee superimposed onto slice 19 illustrating the similarity between the shelf trend in Taylor's model and the low gamma ray trend from the slicing results.