TITLE

**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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PRINCIPAL AUTHORS:

JAMES R. WOOD, T. J. BORNHORST, S. D. CHITTICK - MICHIGAN
TECHNOLOGICAL UNIVERSITY, HOUGHTON, MI

WILLIAM B. HARRISON, WESTERN MICHIGAN UNIVERSITY, KALAMAZOO,
MI.

W. QUINLAN, E. TAYLOR, CRONUS EXPLORATION COMPANY LLC,
TRAVERSE CITY, MI.

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MICHIGAN TECHNOLOGICAL UNIVERSITY
1400 TOWNSEND DRIVE
HOUGHTON, MI. 49931

ABSTRACT 1

A principal goal of the Budget Period I was to demonstrate that surface geochemistry could be used to locate bypassed hydrocarbons in old fields. This part of the program was successful. A surface geochemical survey, employing 5 different techniques, was carried out in the Spring and Summer of 2000 and a demonstration well, the State Vernon & Smock 13-23 HD1 (permit number: PN 53945) was drilled in Vernon Township, Isabella County, Michigan in the late fall of 2000. A demonstration well was selected and drilled based on geologic considerations and surface geochemistry.

Over 460 soil samples were collected and analyzed over the drill site. A good anomaly was detected near the proposed well site and the demonstration well, the Smock 13-23, was drilled to a depth of 3157 feet by November 17, 2000. Two laterals were drilled, and hydrocarbons were located in a zone approximately 175 feet in length. However, it was determined that the pay zone was too small and difficult reservoir conditions (water production) prevented putting the well in production. The Smock 13-23 was shut in and abandoned January 15, 2001. A post-mortem determined that the main reason the well was not economic was because the zone was nearly completely flushed by earlier recovery operations. The post mortem also revealed the presence of an unmapped shale plug crossing the first lateral. It appears that this shale was detected by the geochemical survey, but its significance was not appreciated at the time. It is possible that sections of the well were faulty, "porposing" up and down so as to create water blockages.

We are continuing to use the Vernon Field and the demonstration well to calibrate the geochemical data. Eventually, this study may provide a standard site that can be used to test and calibrate geochemical anomalies, something that does not presently exist. A postmortem report on the well, including the geology and geochemistry used to site the well, is presented in Appendix I. Five geochemical techniques have been tested in Phase I. These include surface iodine, microbial, enzyme leaching, soil gas and subsurface iodine. We are most comfortable with the results of the microbial surveys but feel that direct measurement of soil gas is the best method if analytical difficulties can be overcome. The reason the microbial surveys are presently favored is because they provide a logical, consistent picture that is easy to interpret and easy to explain. This in turn is because the microbial anomaly is manifested as an "apical" as opposed to an "edge" or "halo" anomaly.

Several lessons were learned during Phase I activities. The main one was that surface geochemistry could locate anomalies over old fields such as Vernon. We also learned that horizontal drilling has advantages and disadvantages in situations such as this. On the plus side, it does provide a means to probe for pockets of bypassed oil, but it is expensive relative to vertical (or slant wells?) and is difficult to control in a narrow pay zone. We tentatively conclude that horizontal wells do not provide a cost-effective solution in this setting and suggest that geochemical anomalies be investigated via a single vertical well or multiple vertical wells.

ABSTRACT 2

We are requesting that this project, DE-FC26-00BC15122, be continued from Budget Phase I into Budget Period II. The principal goals will be to extend the geochemical work to new carbonate reservoirs in varied geologic settings and test the models by drilling demonstration wells. The proposed duration of Budget Phase II is 24 months. Geochemical surveys will be run throughout the period. Demonstration wells will be drilled at the rate of one every 6 months. Each well will be completely evaluated and the post mortem conducted prior to drilling the next well. This will ensure that lessons learned can be applied to each new well. At least two wells will be drilled in the Michigan Basin to test new locations and anomalies. One to two wells may be located outside the Michigan Basin in other Shallow-shelf carbonate environments to extend the technology outside the Michigan Basin. The Williston Basin in Montana- N. Dakota is a possible candidate.

The original proposal to DOE stated that “Wells will be drilled in each of the three budget periods: one characterization well in Budget Period #1 and 1 to 4 demonstration wells in Budget Period #2.” We will continue with that basic plan. We are committing to 4 demonstration wells in Budget Period II, all of which will vertical or slant wells. We propose to drill 4 vertical wells at (nominally) \$50,000 each and increase the geochemical task by \$50,000 to include more sampling. This is in response to lessons learned in Budget Phase I.

The justification for this change is that the results of Budget Phase I demonstration well showed that horizontal wells are not cost-effective in testing surface anomalies. Now that the geochemistry has the ability to define probable field extents, the main requirement of the well is to confirm the anomaly and determine the thickness of the pay zone. Once these parameters have been determined, the demonstration is complete and the operator can make the decision of whether or not to develop the prospect. Additional details evaluating the relative merits of horizontal versus vertical wells in this environment (shallow-shelf carbonate) can be found in the Project Evaluation Report.

Geochemical surveys will include several techniques, including microbial and soil gas. New sampling technologies and instrumentation will be evaluated and tested to ensure that the latest developments are reported to the industry. Research will be conducted, via graduate student theses, as appropriate. We anticipate conducting detailed geochemical surveys at a 50-meter spacing in the vicinity of each proposed well, and regional or countywide surveys on a 500-meter spacing. Both of these techniques were evaluated and proven best practices in Budget Phase I.

Deliverables in Budget Phase II will include detailed reports of the geochemical surveys and all drilling, including post-mortem reports. Results will be reported on an on-going basis to the industry via technology transfer on a local and national level. Workshops will be offered under the auspices of the PTTC, as in Budget Phase I, and all data will be made available to the public domain.

DISCLAIMER

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Figure 2. Structure contour map on top of Dundee Formation, Vernon Field, MI.

Figure 3. Structure contour map on top of Dundee Formation in vicinity of Vernon Field showing nearby fields and overall structural setting.

Figure 4. Surface geochem anomaly map for Vernon Field (microbial).

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SECTION 1. EVALUATION OF BUDGET PHASE I

Introduction

In this section, we discuss the goals of Budget Period I, the work done and the results obtained are discussed. . In the second section we discuss the main lessons learned in Period I. Supporting material, including the details of the post-mortem on the demonstration well, the Smock 1-23, and the geochemical results, are given in appendices I and II.

In general, the Phase I effort supported the project as expected. The surface geochemistry did identify a good anomaly that was confirmed on drilling. The failure of the well to produce commercial amounts of hydrocarbons has been traced to previous production and difficulties in positioning the horizontal leg of the well (Appendix I). We also worked out protocols for sampling and investigated the effect of grid spacing on detecting and interpreting anomalies (Appendix II).

Goals

The primary goal in Phase I was to (a) locate hydrocarbons using surface geochemistry and (b) test the predictions with a demonstration well. A consortium consisting of Cronus Exploration (Traverse City, MI), Michigan Technological University (Houghton, MI) and Western Michigan University (Kalamazoo, MI) successfully conducted the geochemical surveys and drilled a demonstration well.

In Phase I of the project, the consortium began the redevelopment of the Vernon Oil Field, located in Vernon Township T16N-4RW, Isabella County, Michigan (Figure 1). The initial well, the Smock 13-23 (Figure 2), failed to produce hydrocarbons although what appeared to be good shows were noted in the drill cuttings. Surface geochemistry surveys conducted located several anomalies that could be tested, including one over the Smock 1-23 demonstration well and another over the proposed as an extension of the field, the Bowers 1-25, (Figure 2).

The producibility problems at Vernon Field, and other similar Dundee Fields (Figure 3) are first locating remaining oil, then characterizing the reservoir architecture (e.g. structure, alteration and facies distribution). Preliminary cost analysis carried out in the pre-planning stages of this study showed that 3D seismic is too expensive for this type of project (the cost is comparable to the entire drilling operation), yet the presence or absence of hydrocarbons needs to be better known prior to drilling. Recent advances in surface geochemistry suggested that this technology is ready for application in recovery operations. It is cheap relative to seismic but needs refinement. The importance of new sampling technologies such as SPME (Site Specific Micro Extraction) fiber sampling and new instrumentation (GCMS – Gas Chromatograph-Mass Spectrometry) which have

made direct sampling and identification of hydrocarbons released from the reservoir to the soil possible, cannot be overemphasized.

A goal of using advanced 2D seismic technology in this project was postponed to Phase II to allow more time to design the survey and integrate it with the surface geochemistry. Drilling schedules, dictated by expiring leases, did not permit us to implement both a seismic and surface geochemistry program in Phase I, but we plan to do so in Phase II. In this case, having subsurface control through 300+ wells pretty well defined the subsurface anyway.

Accomplishments

The main accomplishment of this Phase was producing the anomaly map of the surface geochemistry at Vernon Field. Figure 4 shows the results of the survey for the microbial data. The red area is positive anomaly and the blue is negative. The black crosses are sample points. Note that the area near the demonstration well are on the closest grid spacing (50-meter) and give excellent definition of the anomaly. The two yellow lines are the surface trace of the two laterals. The long lateral proceeds nearly due East from the surface location and passes through several anomalies. The second, shorter, lateral proceeds to the NE and stops short of the better part of the anomaly. The reason for this is that the 50-meter grid was not used to map the anomaly until the post mortem. The original grid spacing did not resolve the anomaly as well as shown in Figure 4; hence the decision to stop short of the better region indicated by surface geochemistry was due to lack of data at the time of drilling. This is one of the primary lessons learned from this well: sample over the well site on a 50-meter grid.

We intend to test the anomaly indicated by the yellow symbol in Figure 4 with the 2nd demonstration well (Bowers 1-25). This microbial geochemical high mapped in Figure 4 is supported by good geological indicators, mainly structure and possible presence of a dolomite reservoir facies, and is the last good opportunity we have found at Vernon Field.

It was also necessary to overcome resistance to application of surface geochemistry in the Michigan Basin. Surface geochemistry has had a spotty history in the oil industry and has been tried many times before. This difference here is that better analytical instruments and more open discussion and presentation (via technology transfer workshops and talks) have rekindled interest. At this time one major oil company is actively using surface geochemistry in the Michigan Basin and several more independents and small contractors, including this group, are testing it. The most useful technology we have developed or used appears to be the SPME surface geochemistry; it has potential application as a more effective and economic “risk reducer” in Michigan Fields similar to Vernon Field as well as elsewhere. The technique is inexpensive compared to 2D or 3D seismic and can be done quickly (typical turn around of 1 week or less).

Additionally, the results from the drilling of the Smock well will be of considerable interest to the local Michigan Gas and Oil Industry, particularly the findings on the contact irregularities between the Dundee and Bell Formations. The drilling strategy,

which included using multiple laterals to probe for bypassed oil, provided a template for probing for reserves in these types of formations.

The Smock well supported the project objectives in that it provided key data leading to a new geological model for the Vernon Field and pioneered a new approach to locating reserves and may help reduce drilling risk based on surface geochemistry surveys. The initial surface geochemistry microbial data suggested weak hydrocarbon anomalies were present but the headspace gas data strongly suggested that the location was poor. The Smock demonstration well showed that HCs were present in the Dundee horizon, but the distribution was spotty. Surface geochemistry continues to emerge in this project as a more valuable and flexible tool than originally expected. We still feel that the surface geochemistry is a viable and important component of the study and may yet result in reducing risk in locating these types of prospects.

SECTION 2. EVALUATION CONCLUSIONS

The surface geochemistry emerged as the most successful aspect of Phase I. Good geochemical anomalies were detected and mapped at Vernon Field. Although the first demonstration well was not a commercial success, it did confirm the geochemical anomalies and did lead to an improved understanding of the geology of the Vernon reservoir, particularly the role of shales and shale plugs. And it did support the notion that surface geochemistry is a viable tool for reducing drilling risk. There seems to be no doubt that leaking hydrocarbons from reservoirs at depth were detected both indirectly by the microbial data and directly by the soil-gas data. However the results indicate that the data has to be properly calibrated for local conditions and that a good sampling protocol is essential. An 8 x 8 grid spacing (64 samples/sq. mi) is adequate for most purpose but may not be sufficient for optimal signal resolution, e.g. there may be more signal than can be sampled on an 8 x 8 grid. A smaller, tighter grid (16 x 16) was used to resolve the shale plug found over the demonstration well.

It appears that the soil-gas data was telling us more than we realized. Reexamining the data suggests that it was telling us that the prospect was likely to be poor, but we did not fully appreciate the importance of the data and did not collect enough samples. In addition, we probably did not use a tight enough grid spacing over the prospect. A 100 m spacing may not be tight enough to resolve all the features that can be extracted from surface geochemistry and suggests that 50 m spacing (or less) over selected features may be necessary.

What did we learn?

The most important lesson learned from the Smock well was that the geochemical data is important, particularly the soil-gas data. Good anomalies can be obtained over these fields, the challenge is to learn to use them. Along these lines we must learn to calibrate the data, particularly with regard to background, and we need to develop interpretive skills. A corollary is that the sampling protocol is important, especially the grid spacing, and it is necessary to establish a reliable background locally.

We did learn that the Vernon Field is releasing a geochemical signal that can be detected and quantified. This may be the most significant aspect of the demonstration, particularly if we can put these lessons to work on the second well, which is near enough and similar enough to the demonstration well that all the data and lessons should be applicable.

From a geological perspective, we learned that the Dundee surface is not only diagenetically altered but that it is locally laced with sinkholes and shale canyons that can make or break a play. Our understanding of the scale and frequency of the shale breaks in the Dundee Formation is greatly improved.

Several unexpected geological results were obtained from the Smock well, including the confirmation that the top of the Dundee Formation is highly irregular at the Bell Shale contact. Cross sections prepared using the new data from the demonstration well suggest

that a large shale plug is in the vicinity and may be due either to karsting or faulting (?). While the microbial geochemical surveys continued to define the extent of Vernon Field, the new large anomaly to the Northeast, termed the Isabella Road anomaly continued to grow as the sampling program expanded. Analysis of the iodine and enzyme leach data continued and the enzyme leach data continued to show promise as a useful tool. Further work is in progress on these samples, and we are now attempting to use SPME technology on the samples to see if hydrocarbon gases can be detected. This method would compliment the direct measurement of soil gas mentioned above in that it would be detecting the paleo gas signature if successful. That is because the enzyme leach would release material frozen into the solid diagenetic phases as the field developed.

The results from the drilling of the Smock well will be of considerable interest to the local Michigan Gas and Oil Industry, particularly the findings on the contact irregularities between the Dundee and Bell Formations. The drilling strategy, which included using multiple laterals to probe for bypassed oil, provided a template for probing for reserves in these types of formations.

The most useful technology developed appears to be the SPME surface geochemistry; it has potential application as a more effective and economic “risk reducer” in Michigan Fields similar to Vernon Field as well as elsewhere. The technique is inexpensive compared to 2D or 3D seismic and can be done quickly (typical turn around of 1 week or less).

The Smock well supported the project objectives in that it provided key data leading to a new geological model for the Vernon Field and pioneered a new approach to locating reserves and may help reduce drilling risk based on surface geochemistry surveys. The initial surface geochemistry microbial data suggested weak hydrocarbon anomalies were present but the headspace gas data strongly suggested that the location was poor. The Smock demonstration well showed that HCs were present in the Dundee horizon, but the distribution was spotty. Surface geochemistry continues to emerge in this project as a more valuable and flexible tool than originally expected. We still feel that the surface geochemistry is a viable and important component of the study and may yet result in reducing risk in locating these types of prospects.

More follow-up wells need to be sited and drilled. Lessons learned from the first well need to be digested and put to work in implementing the second demonstration well. In particular, we need to look carefully at reducing the risk of encountering economic pay zones. While the surface geochemistry seems to have potential for locating hydrocarbon anomalies, we still need to develop ways to access the potential for successful development of an anomaly. More geochemical surveys need to be conducted at Vernon field and elsewhere, building on the knowledge and expertise gained from the first year studies. Laboratory techniques need to be developed to collect and analyze gases collected directly from the soil horizon.

What should have been done?

Following the drilling of the Smock well, it appears that we could improved the chances for an economic success by drilling inexpensive vertical wells. While the lateral wells allowed probing for reservoir rock, the same end could have been achieved by drilling “slant” vertical wells at a lower cost. In cases where the pay zone is narrow, i.e. on the order of 1-15 feet thick, a vertical well has a better chance of producing since it hard to keep a horizontal well in the zone. A little water can effectively kill a lateral.

Also, the geochemical surveys should have been conducted on a tighter grid spacing (50 meter), particularly over the well site and techniques based on direct detection of soil gases, such as headspace gases, should have been emphasized. It would have helped to have had a better baseline or background. Not knowing what constituted an anomaly was a handicap. Although we have now rectified that, we should have carried out the initial line survey several miles further. In that regard, having a library of surveys as reference will be a huge advantage to future surveys.

We should have also been more careful in looking for hydrocarbons in formations as we drilled, even near the top, which was thousands of feet from the target. The reason is that we cannot tell the depth of an anomaly, only its presence and extent. A shallow source for our anomalies cannot be ruled out and we should have tested known hydrocarbon horizons, such as the Marshall, on the way down.

SECTION 3. PLANS FOR BUDGET PHASE II

The following is a detailed description of plans for Budget Phase II. The first part contains the plan as originally submitted to DOE. Changes are denoted in italics. The revised plans for Budget Phase II are summarized in “Revised Tasks and Goals” (following).

Original Proposal

“We intend to examine a number of Class II fields in the U.S., particularly in the Michigan Basin. Anomalies will be mapped prior to drilling, then repeated after producing to see if any temporal changes have occurred. It is anticipated that surface geochemistry will provide operators with an economic alternative to 3D seismic surveys as far as indicating the presence or absence of hydrocarbons. This project will also address the problem of efficiently draining the reservoirs by trying to use surface geochemistry to monitor changes in reservoir content with time.

Proposed field activities include an active drilling program supplemented by repeated surface geochemical surveys. Wells will be drilled in each of the three budget periods: one characterization well in Budget Period #1 and one to four demonstration wells in Budget Period #2. At least one monitoring well will be drilled in Budget Period 3, and perhaps more. Well 3 and all remaining wells will be drilled without government assistance. The surface geochemistry surveys will guide the placement of the wells. An evolving geologic model for the development of the field will be assembled using data and information from wells as they are drilled and from repeated surface geochemical surveys.

Surface geochemical surveys will be run to locate hydrocarbon anomalies. Results will be combined with the seismic surveys and with conventional subsurface geological mapping to precisely locate the demonstration well and further characterize the reservoir. These surveys will be run over several other fields and some will be re-run over Vernon Field to test the repeatability as well as to see if reservoir changes due to production can be detected. Multi-lateral horizontal wells will be used to probe the reservoir and produce any hydrocarbons. These wells will be drilled using coiled tubing technology and the latest in horizontal drilling technology. A comprehensive suite of well logs, including image logs will be run on the relevant portions of the wells.

The technology transfer approach will include characterization of 3-4 more shallow-shelf carbonate fields and communication of all results as they are acquired. The principal technology transfer mechanisms will be workshops (in conjunction with PTTC when appropriate), publication and oral presentation of papers in the technical literature and distribution of reports and data on the Internet and via CD-ROM.

The additional fields to be characterized include Deep River, North Adams, Pinconning, Skeels, Northville, and Clayton. All these fields are reservoirs that developed as isolated pods of dolomite encased in regional tight limestone in the upper portion of the Dundee. These fields have some of the highest recoveries per acre of any reservoirs in the

Michigan basin (Chanpion, 1969, Catacosinos et. al. 1991). Oil recoveries range from 5000 to 28,000 barrels per acre. These reservoirs have produced over 50,000,000 barrels of oil. Recoverable hydrocarbons that can be attributed directly to the wells drilled in this project are estimated at 1,500,000 barrels of oil utilizing a 50% recovery factor.”

Revised Tasks and Goals

We do not plan to deviate significantly from the original plan for Budget Phase II. Two areas where there will be slight deviations are:

1. To drill vertical or slant wells instead of horizontal wells, and
2. To incorporate improvements in plans for the geochemical sampling and analysis

The next well to be drilled is the East Vernon Prospect, the Bowers 1-25. This prospect is described in detail below (same as original proposal). We are still discussing this project in light of recent geochemical data that shows a positive anomaly in the area but also show a low near the proposed well. We may try to re-site the well to better test the anomaly. In any case we will test the formations on the way to the Dundee to see if there is any possibility of a higher source in the area.

East Vernon Dundee Prospect: The Bowers 1-25 HD

As a follow-up to the Smock (note: originally Stough) well, the Bowers 1-25 HD 80 acre unit (SW $\frac{1}{4}$ SW $\frac{1}{4}$ of section 24 and the NW $\frac{1}{4}$ NW $\frac{1}{4}$ of section 25 of Vernon Twp.) is proposed to evaluate a 200 acre undeveloped prospect area adjoining the Vernon field to the east (Figure 2). The surface geochemical anomaly associated with this site is mapped in Figure 4 of the accompanying document (Phase I Evaluation). The anomaly is more fully discussed there as part of the Phase I accomplishments.

The Vernon Dundee production is associated with dolomitization of the upper Dundee (Rogers City) interval. The dolomite body as defined by the existing well control to date encompasses some 2000 acres. The extent of the dolomitization is considered to be fracture controlled. Immediately surrounding the dolomite trend are wells in which the dolomite is overlain by dense limestone cap rock. The thickness of the cap rock in this border area ranges upwards to 75 feet. Wells within this thickness range generally exist within $\frac{1}{2}$ mile of the dolomitized area. Further out from the dolomitized area, the cap rock thickness is 100 feet or more as regionally the 350 foot Dundee section consists predominantly of limestone in the prospect area.

The Bowers 1-25 HD attempts to extend the Vernon field eastward. The existing well control suggests the fairway of dolomitization continues in this direction. The 200 acre prospect is rather well defined by existing Dundee penetrations with anomalously thin or no limestone cap rock. These wells include the 3 Dundee oil wells on the Verette lease (SE $\frac{1}{4}$ SE $\frac{1}{4}$, 23). Drilled in 1933, the 40 acre tract cumulated 132,558 barrels before abandonment in 1938. The Verette #1 (NW $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$, 23) was one of the strongest

wells in the field, completing for 5000 BOD natural. The reservoir dolomite development is apparently significant in the area of this well bore. The Verette production is the eastern most in the field to date. It is important to note the Verette #2 (NE¼ SE¼ SE¼, 23) did not encounter any limestone cap rock. This establishes upper Dundee dolomitization within 330 feet of the Bowers 1-25 HD unit boundary.

Along with the Verette wells, four dry holes located on the east side of the Vernon field define the East Vernon prospect. All 4 wells have anomalously thin limestone cap rock sections. The cap rock sections penetrated in these wells are similar to the proximal wells, which immediately border the Vernon dolomite trend in its entirety. As shown on the prospect maps, the trend of upper Dundee dolomitization is interpreted to extend through the Verette lease and into parts of sections 24 and 25.

Another important geological aspect of the East Vernon prospect is the fact that it is favorably positioned at the updip margin of the dolomitization. The prospect area borders the southern lateral seal. Structurally, the White is even with the best wells in the field. As a result, expected maximum gross hydrocarbon column thickness is 45 feet.

The Bowers 1-25 HD prospect is an ideal application for horizontal drilling as the technology offers an excellent method to explore for upper Dundee porosity across a large area. The intended TVD for the initial leg of the horizontal hole will be -2920 subsea. Anticipated length of the lateral is 1800 feet.

Recoverable reserves for the East Vernon prospect are estimated at 1,500,000 barrels of oil utilizing a 50% recovery factor. The reserves estimate benefits from the fact the prospect is positioned at the updip limit of the Vernon reservoir. Because the prospect is located upstructure, drainage from the old wells is expected to be minimal with the oil-water contact remaining at or near -2950 subsea. For the Bowers 1-25 HD test, recoverable oil reserves are estimated upwards to 350,000 barrels.

Deliverables

Deliverables in Budget Phase II will include detailed reports of the geochemical surveys and all drilling, including post-mortem reports. Results will be reported on an on-going basis to the industry via technology transfer on a local and national level. Workshops will be offered under the auspices of the PTTC, as in Budget Phase I, and all data will be made available to the public domain.

Demonstration Well #2

As part of the scheduled deliverables for this project, a 2nd demonstration well (the White 1-24, see above) is currently in the late design stages and is nearly ready for permit application. This well is also in Vernon Field, Isabella County, Michigan. The object of the well was to test the ability of surface geochemistry to locate anomalies. It was

anticipated that the flexibility offered by the horizontal technology would permit probing the subsurface for pockets of by-passed oil via lateral offshoots. This was thought to be necessary due to the known production difficulties arising from the highly irregular contact between the top of the Dundee Formation and the bottom of the overlying Bell Shale. Although this proved to be true, post-mortem analysis revealed that the lateral was not cost effective and that better, more economic results could be achieved through vertical wells, using “slant” wells to probe off vertical if necessary. This arrangement will also permit core to be taken more easily if necessary.

Demonstration Well #3

Although demonstration wells beyond #2 (above) are not as far along, a strong candidate for the demonstration well #3 is the shallow shelf debris reef in the Manistee area. Preliminary surface geochem work shows a strong anomaly in the areas of interest, and our industry partners are interested in drilling it. This area is far removed from the sites of demonstration wells #1 and #2 and would target a new and different play. There is a good possibility that this well can be drilled in the next 12-14 months.

Demonstration Wells #4 and #5

No sites have been selected for demonstration wells #4 and #5. These wells will be drilled in the 2nd year of Budget Phase II and will likely be affected by the results of the two previous wells. We do not anticipate any problems in getting these wells drilled on time.

SECTION 4. PLAN SUMMARY

Budget Phase I proceeded pretty much as planned. Good results were obtained, particularly with regard to the geochemical work, and Budget Phase II is on line to take up this fall. Sampling has continued over the summer of this year in anticipation of continuing the project and two possible sites for demonstration wells #2 and #3 have been identified.

Although the first demonstration well was a commercial failure, it did lead to an improved understanding of the geology of the Vernon reservoir, particularly the role of shales and shale plugs. And it did support the notion that surface geochemistry is a viable tool for reducing drilling risk. There seems to be no doubt that surface seepage of hydrocarbons was detected both indirectly by the microbial data and directly by the soil-gas data. However the results indicate that the data has to be properly calibrated for local conditions and that a good sampling protocol is essential. An 8 x 8 grid spacing (64 samples/sq. mi) is adequate for most purpose but needs to be increased to a tighter 50-meter from maximum resolution, such as the shale plug found over the demonstration well #1.

It appears that the soil-gas data was telling us more than we realized. Work is in progress to obtain equipment that will let us routinely analyze for soil gases in the C1 – C20 range. A student has begun a Masters Degree on this topic and this will ensure that a good component of research is added to this task. A gas chromatograph has been obtained that will enable us to take measurements in the field and in the lab. Preliminary results show that the instrument can detect hydrocarbon gases in the 100 ppb range and test on actual samples have picked up C1 (methane) through C6 (hexane). Vendors are claiming to be able to detect up to C20 hydrocarbons and one goal will be to investigate this. We have also obtained a suite of crude oil samples from field in the Michigan Basin and will analyze these gases as well. We hope to show a relation between the composition of gases coming from the crude to the soil samples.

The geochemical work is emerging as a primary goal of this project. We need to develop a technique that is robust enough for operators to do the sampling analysis and interpretation themselves. The goal is to try to put a package together that will enable these operators to routinely incorporate surface geochemistry as part of their prospect evaluation. If this is going to happen costs will have to come in the range of \$1000 - \$2000/square mile, since we know that 2D and 3D seismic surveys that cost 10-20 times as much are out of reach for this type of project.

As it stands now, we estimate that a detailed survey covering 1 square mile requires an 8x8 grid or 64 samples. If sample collection and analysis cost can be kept to nominally \$20-\$40/sample, the cost would be in the range of \$1250 - \$5000 per square mile. Reconnaissance surveys can be run on a 4x4 grid (per square mile) or about \$300 - \$600/

sq. mi. This would be in the range of most small operator's budgets and almost certainly would be done routinely if we can demonstrate that the technique works.

APPENDIX I

Post-mortem on The State Vernon & Smock #13-23 HD1

The State Vernon & Smock #13-23 HD1 demonstration well was spudded on October 5, 2000. The target was the top of the Dundee Formation (Figure 2) at a depth of about – 2900 feet subsea. (Reported depths are all subsea except where indicated.) The play was to find hydrocarbons in dolomitized reservoir rock that had not been swept by previous recovery operations. It was expected that the well would encounter either the tight limestone of the unaltered Dundee or the dolomite facies of the reservoir. Instead, however, the well encountered shale that has been interpreted as a shale plug, possibly deposited in a sinkhole developed on top of a karst surface (Figure A-1). Mapping indicates that the plug is a maximum of 40 feet thick near the well and 5-20 feet thick along the well trajectories (Figure A-2).

The first lateral reached the top of the Dundee Formation at –2902 feet on October 26. Seven-inch casing was set at 4229 MD and the lateral continued another 980 feet to 4982 MD. The trajectory of this lateral is shown in Figure A-3. This lateral encountered shale immediately upon entering the target zone and was deviated upward then down in an effort to escape the shale. As Figure A-3 shows this effort was unsuccessful. However, the well was thought to have hit the porous dolomite hydrocarbon zone (PDHZ) in the last 50 feet (Figure A-3) between depths of -2915 to –2920. The only hydrocarbon show was a gas show of 320 units measured at 4192 MD just at the Dundee – Bell Shale contact. This well was abandoned on November 3rd.

Based on information obtained from the first lateral, a second lateral was drilled on November 4th. This well was kicked off from the casing point at 4229 feet MD and targeted for the top of the PDHZ encountered in the first lateral. Accordingly the well was deviated down (Figure A-2) and to the NE (Figure A-1). At 8 feet below the first lateral, the well encountered the PDHZ at about 4400 feet MD and attempted to follow the contact another 230 feet to 4630 feet MD (Figure A-3) where it again encountered shale. At this point drilling was stopped on November 6th and attempts were made to produce the interval based on good hydrocarbon shows from 4405 to 4630 feet MD. Unfortunately, despite the good reservoir rock and numerous oil shows, the interval could not be produced and was abandoned January 12, 2001. The reason for the failure to produce is tentatively assigned to the hypothesis that the interval was previously drained by earlier wells.

Revised Geology based on the State Vernon & Smock #13-23

It is possible to construct a detailed geologic model that fits the observations from the pre-existing wells and the demonstration well. We presently think that a karst model best fits the data, but this is open to other interpretations. The best way to visualize the karst model is through cross-sections taken at approximately right angles. Figures A-3 and A-4

are two such cross-sections. Figure A-3 is an East- West cross-section taken approximately along the well trajectories, that is approximately along the trace of the lateral offshoots of the demonstration well shown in Figures 2, A-1 and A-2. Figure A-4 is a North-South cross-section taken along the line of section indicated in Figure A-2. Note that the vertical scale is approximately the same in both cross-sections but the horizontal scale is smaller in Figure A-4 than in Figure A-3 by a factor of roughly 2X.

Together these figures suggest that the overall geologic model for the Upper Dundee at Vernon Field is a karstic topography with mud filling sinkholes or small canyons in the secondary dolomite facies but not the original limestone facies (Figure A-4). It may seem curious that the sinkholes are confined to the dolomite facies, but a logical scenario is that the fluids that dolomitized the limestone simply followed the preexisting joints and fractures that developed the karst surface. It is possible that this is a faulted topography with some with minor (10-20 feet?) offsets. In any event, this model fits the observations and is consistent with what we know about the Dundee Formation in general.

At Vernon Field, the top of the Dundee is nearly flat, varying by about +/-5 feet over much of the surface except at the edges where it drops fairly abruptly by 30-50 feet. The contour map in Figure 2 shows a flat plateau at approximately -2900 feet with maximum depths or depressions to -2950 feet. The topographic lows on the Dundee surface roughly coincide with the extent of the shale-filled caverns mapped in Figure A-2.

APPENDIX II. SURFACE GEOCHEMISTRY

A surface geochemistry program was initiated at Vernon Field in support of this project. The surveys were designed to examine four different techniques based on a literature search and discussions with vendors. The four 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. Although we started with no bias toward or against any one technique, we moved to an initial position favoring the microbial data, for reasons outlined below. However, we are not yet committed to any one technique and will continue to examine the others as well as new technologies that appear promising.

The microbial technique is based on the premise that microbes living in the soil are unique depending on their food (energy) source. Microbes that thrive on light hydrocarbon gases (C1 – C4) in particular are known to feed exclusively on these gases, even to the extent that one microbe consuming only one gas. The technique is based on culturing these microbes in a laboratory for a period of time on a special substrate and then counting the microbe population. Samples are collected 8 inches below ground surface and cultured within 48 hours of collection. The main assumption is that the microbes will be present if the gases are present and absent otherwise. Since C2 – C4 hydrocarbons are widely thought to originate only from gas and oil accumulations, the presence of microbes specialized to feed on these gases is taken as evidence of a migration of hydrocarbons from the reservoir to the surface.

We presently favor the microbial technique because it gave a positive (apical) anomaly that is easy to interpret. In addition, the mechanism is conceptually simple and interpretation is straightforward: contour maps show highs over the anomaly. Another technique that might be as good or even better, direct measurement of soil gas hydrocarbons, was not pursued this avenue as vigorously due to two factors: the cost of analysis (\$50 – 200/sample) and the difficulty of sample collection (samples are taken from 3-4 foot depths). However, this technique might have warned us that the demonstration well was located over a poor site (see below).

Sampling

An area of Vernon Field approximately 2-3 square miles in area was sampled over a period of six months from May 2000 to November 2000. Four separate sampling trips were taken and over 360 sample sites visited. Multiple samples were collected at several sites.

The first trip was reconnaissance in nature. Fifty sites were visited, including four over the site of the demonstration well, and samples were collected for surface iodine, enzyme leach, microbial and soil-gas. Samples were analyzed for surface iodine, enzyme leach and microbial analyses at all 50 sites. Only six soil-gas analyses were collected and run,

but two of these were over the well site. The samples were mostly collected in a line-profile along Mission Road over the known extent of the Vernon Field. The goals were to see which, if any, of the techniques would show the best anomalies and which would be best for subsequent sampling trips. In brief, all four techniques showed anomalies of one degree or another, but the microbial data appeared the most promising and was tagged for subsequent emphasis, although surface iodine and enzyme leach data continued to be collected.

The microbial Mission Road profile is shown in Figure B-1. Samples were collected at 200-meter (600 feet) spacing. It is apparent that the high values occur over the known extents of Vernon Field, and the samples collected over the proposed drill site initially appeared to show anomalies. Data from the other geochemical techniques were less convincing (except for the few soil-gas samples, see below) and we concentrated on collecting microbial samples over the rest of the target areas.

Sampling Strategy

On the first sampling trip, samples were collected along a line profile (1D survey) at 200 meter (600 feet) spacing (Figure B-1). It was necessary to establish a grid spacing that would adequately sample the anomaly without oversampling. One requirement we attempted to meet was to sample one square mile per day. As mentioned, the MRP was sampled at nominally 200 meters (600 feet). Although this spacing appeared adequate, it was decided tighter spacing was needed over the fields and a spacing of 100 meters was adopted for the grid in both directions. This spacing works out to 8 samples per mile or 64 samples per square mile. This spacing was found to produce good contour maps of the microbial anomalies but may not be sufficiently dense to resolve all features.

Assuming 20 minutes to walk 1 mile, then 8 samples per mile leaves 5 minutes per station if we want to cover 1 mile in an hour. Microbial samples can be collected in this time, including reading and recording the site location. We found that one man could easily make four 1-mile traverses per day e.g. cover $\frac{1}{2}$ square mile. The optimal sampling team was found to be a team of two men sampling 1 square mile per day, each collecting 32 samples.

Surface Geochemistry

Results for the 2D microbial survey over the Vernon Field study are shown in Figure B-2. The sampling locations are indicated and the contours represent values of microbial density as cultured in the laboratory from the field samples. In general, the data show lows to the west over the part of Vernon Field that is still under production, increasing to the East with a still unresolved high outside the field to the Northeast. This high nominally lies along Isabella Road and has been termed the Isabella High. The origins of this high are unknown, but may be due to gas in the Stray Formation. Geologic data

suggests that is unlikely to be due to a Dundee source but this has not been definitively ruled out.

There is a microbial high over the demonstration well, but statistical analysis suggests that this should be regarded as a marginal anomaly. Data collected to date over the site of the second proposed well, the Bowers #1-26 in the East Vernon Prospect (Figures 2 and 3) show a similar anomaly.

APPENDIX III: BUDGET PERIOD I SOW

Budget Period #1

<u>Task 1 Project Management – J. Wood</u>

Description of Work Coordinate all aspects of the project between Michigan Technological University (MTU) at Houghton, Michigan, Western Michigan University in Kalamazoo, MI and Cronus Energy in Traverse City, MI. Produce a working document that will outline the project in detail as well as set a schedule of visits and meetings. Coordinate all necessary meetings and will serve as the central repository for all project deliverables and reports.

Rational Management is a key aspect for a success in a project such as this. Experience in dealing with the various Federal, State and Universities entities is valuable as is continuity in which the same managers that start the project will finish it. This management team is experienced and has kept the team intact during previous project of this nature. An important function of the project managers is to prompt team members, particularly those at remote sites, to stay on schedule and submit deliverables and attend meetings.

Subtask 1.1 Technical Aspects - J. Wood

Prepare and enforce policies regarding the management of all technical tasks, including reports to DOE, task assignments, management of Web sites, newsletters, and internal management policies that will ensure the smooth functioning of the project team. Travel will be coordinated at this level as well as expenditures of equipment and student support.

Subtask 1.2 Financial Reports and Accounting - A. Hein

Prepare and submit all financial documents related to the project to DOE and to MTU as required, including all monthly, quarterly and annual statements and documents. Keep copies of all expenditures, bills, invoices and related financial documents that concern this project, including personnel time and pay. Established procedures will be used for tracking and payments as well as formal auditing procedures. Wood will monitor and provide oversight on this task and will sign all forms and reports requiring official signature.

Subtask 1.3 Archives - C. Asiala

Materials and reports generated in the course of the project need to be archived in a timely and orderly fashion. It is important to have one person assigned to this task throughout the project and that they be able to retrieve and transmit data, reports, etc. in a timely manner.

Task 2 Reservoir Characterization – W. Harrison

Description of Work Collect, analyze and integrate geologic and engineering data on the Vernon reservoir, particularly structural and stratigraphic data and engineering properties. Determine the reservoir architecture as well as possible prior to drilling the test well. Acquire and interpret 2D seismic line(s). Design, execute and interpret surface geochemical survey(s). Make economic projections and help site wells for development.

Rational Reservoir characterization is the technical key to a successful project, and the reason that most unsuccessful projects fail. Time and effort spent planning and executing a recovery plan prior to drilling almost always pays off in the long run, both economically and technically.

Subtask 2.1 Surface Geochemistry – T. Bornhorst

Design and execute a sampling program to collect soil samples for analyses of hydrocarbon indicators. Make measurements on the samples as appropriate (soil gases, iodine, alteration products, etc. Reduce, display and interpret the data. Make recommendations on siting wells using results. Repeat survey if appropriate to detect changes, if any.

Subtask 2.2 Reservoir Geology – S. Chittick

Obtain subsurface data related to reservoir structure, lithology, thickness, history and produce maps (structural, isopach, production, etc.) of same. Produce overall geologic picture of reservoir, particularly areas likely to contain by-passed oil, and make recommendations on siting recovery wells.

Subtask 2.3 Engineering Parameters- W. Harrison

Obtain engineering and production data on field from previous wells, particularly porosity, porosity distribution, permeability, oil saturation, viscosity, API gravity, etc. Map appropriate parameters on reservoir using geostatistics.

Subtask 2.4 2D Seismic- W. Quinlan

Plan and contract for 2D seismic lines over Vernon Field reservoir. Interact with seismic contractor and oversee data collection. Assist in interpretation and provide relevant data and information to team members characterizing reservoir. Prepare reports, maps and databases as necessary.

Task 3 Analysis and Characterization of Producibility Problem(s) – W. Quinlan

Description of Work Analyze producibility problem(s) at Vernon Field. Use drilling and logging data obtained from new well. Design, permit and drill characterization well. Design and supervise logging program. Consult with team members regarding best location for well, log suite and data collection. Be on site during drilling and interpret

MWD (Measurement While Drilling) data. Conduct flow test if hydrocarbons are encountered. Make decisions regarding placing well on production and best practices for production.

Rational A characterization well is the most important single aid in planning a successful recovery programs in old fields like the Vernon Field where production practices were primitive by today's standards and data are primitive or lacking. It determines whether or not any oil actually remains to be recovered, gives an indication of how much remains, provides data on rock properties and tests the drilling technology. It also provides data on fracture density and orientations and reservoir architecture, particularly on the horizontal leg(s). It may give information on the old oil water contact and whether the reservoir has re-equilibrated to any significant degree.

Subtask 3.1 Drilling – E. Taylor

Supervise actual drilling. Make sure driller follows instructions. Monitor MWD data and make decisions on directing the bit. Contract for and supervise mud logger.

Subtask 3.2 Well Logging – S. Chittick

Make arrangements for logging contractor. Plan logging program. Supervise logging runs. Interpret results and write reports and make presentations. Advise other team members of results as appropriate.

Task 4 Technology Transfer – W. Harrison

Description of Work Transfer of the technology is recognized as a crucial element in this project. Special efforts will be made to deliver the results in a useable form to our target audience through:

- Meetings and personal contacts.
- Workshops and training courses on use of the data and software
- Electronic distribution of results and data on Internet
- Establishing computer links between Michigan Tech and selected companies

Special targets for this transfer are small companies and independents. The program designed to reach this audience involves two key steps: (1) development of case histories and examples that have immediate interest to them, and (2) take these case histories and examples along on the road and demo them at local meetings and in individual offices, face-to-face. This will be a high priority.

Rational: Timely transfer of data and information from this project to others may lead to further development of old shallow-shelf carbonate fields.

Subtask 4.1 PTTC Workshops – W. Harrison

Hold workshops at least annually with the PTTC on topics coming out of this project. Seek the assistance of local PTTC chapters and try to hold workshops in conjunction with

them. Develop case histories and tutorials relevant to project and offer them to intended audience on a regular basis and on demand.

Subtask 4.2 Reports – J. Wood

Publish project results in DOE reports and in scholarly journals. Present results at local and national meeting of geological societies, such as the AAPG.

Subtask 4.3 Newsletter

Publish project results, updates and news in hardcopy and electronic newsletters published by The Subsurface Visualization Lab at Michigan Tech. Place relevant results on Internet in timely fashion.

Task 5 Continuation – J. Wood

Description of Work Prepare reports and documentation for Budget Period #1. Evaluate progress on project and make a decision on whether to ask for funding to continue onto Budget Period #2.

Rational: Project decision points are necessary to formally summarize progress and evaluate prospects for further progress.

Subtask 5.1 Topical Reports – Staff

Preparation and submission of Topical Reports as specified in Attachment C, pp. B-C-7 to B-C-16. Experience in previous Class Projects indicates that the best approach here is to distribute the text of the requirements along with the relevant tables and have the appropriate project personnel work on them and fill in the tables as the project progresses.

Subtask 5.2 Project Review - Staff

Meet with project staff and DOE Project Manager(s) to present results of project through 1st budget period and decide whether to proceed to Budget Period 2.

Subtask 5.3 Renewal Request

Prepare and submit official renewal request to DOE, if appropriate. Revise budget as necessary and update tasks as appropriate.

APPENDIX IV: BUDGET PERIOD II SOW

Budget Period #2

Task 1 Project Management – J. Wood

(see as Budget Period #1)

Task 2 Reservoir Model – W. Harrison

Description of Work Use data obtained in Task 2, Budget Period #1 to construct reservoir model of entire Vernon Field, including previously developed portions. Extend analysis, including data collection and reservoir characterization to 5 – 10 shallow shelf fields similar to Vernon. Draw analogies and point out similarities and differences.

Rational The Class Program is designed in part to assist the introduction of new technology and methodology in one field with the intention that other operators can apply it to other “look alike” fields. This task will further that effort by identifying specific fields that are “look alike” candidates and assembling a public domain database for them.

Subtask 2.1 Surface Geochemistry – T. Bornhorst

Continue to design and execute sampling programs to collect additional soil samples from fields other than Vernon Field for analyses of hydrocarbon indicators. Make measurements on the samples as appropriate (soil gases, iodine, alteration products, etc). Examine different surface parameters from those measured in Budget Phase #1 as appropriate. Reduce, display and interpret the data. Obtain data sets for additional fields and compare and contrast them.

Subtask 2.2 Reservoir Geology – S. Chittick

Work out subsurface reservoir geology for additional “look alike” fields. Produce structure, lithology, thickness (isopach) maps.

Subtask 2.3 Engineering Parameters- W. Harrison

Obtain engineering and production data on additional fields from previous wells, particularly porosity, porosity distribution, permeability, oil saturation, viscosity, API gravity, etc. Map appropriate parameters on reservoir using geostatistics.

Task 3 Field Implementation – W. Quinlan

Description of Work Implement recovery technology at Vernon Field. Use drilling and logging data obtained from characterization well to develop a recovery plan for the entire Vernon project reservoir. Determine number of wells, locations and types (horizontal,

multilateral, etc.) Design, and permit the wells. Select and drill the highest priority well as the project demonstration well. Design and implement a logging program for this well.

Rational A demonstration well is necessary to show that economic quantities of hydrocarbons can be located and produced in these old fields. A key aspect is detecting and sealing zones that produce water. Wells failed in the Crystal Field because they penetrated water (Wood et. al., 1996). These wells will use MWD technology to avoid water and stay as close to top of the reservoir as possible.

Subtask 3.1 Drilling – E. Taylor

(see Budget Period #1)

Subtask 3.2 Well Logging – S. Chittick

(see Budget Period #1)

Task 4 Technology Transfer – W. Harrison

(see Budget Period #1)

Task 5 Continuation – J. Wood

(see Budget Period #1)

FIGURES

FIGURE 1. Location map showing Vernon Field and all oil fields in Michigan producing from hydrothermal dolomite reservoirs (“top porosity”).

FIGURE 2. Structure map on top of the Dundee Formation showing the surface location of the State Vernon & Smock #13-23 HD well and the surface projections of the trajectories of the two horizontal wells.

FIGURE 3. Grayscale contour map of the top of the Dundee Formation near Vernon Field. Other fields shown are Rosebush, Leaton, Wise, and Isabella.

FIGURE 4. Surface geochem anomaly map for Vernon Field (microbial).

FIGURE A-1. Structure map on top of the Dundee Porosity showing the surface location of the State Vernon & Smock #13-23 HD well and the trajectories of the two horizontals. Note that the top of porosity beneath the surface location of the demonstration well lies at –2940 feet (subsea) while the top of the Dundee Formation at this location is –2930 feet (est.).

FIGURE A-2. Isopach map of the Dundee Cap Rock Thickness showing the surface location of the State Vernon & Smock #13-23 HD well and the trajectories of the two horizontals. The probable extent of the shale-filled cavern within the Upper Dundee section is indicated.

FIGURE A-3. East-West cross-section through the Vernon Field at the location of the State Vernon & Smock #13-23 HD well showing the probable extent of the shale-filled cavern within the Upper Dundee section. The trajectories of the horizontal wells are indicated. The surface of the Dundee Formation is drawn and the position of the dense limestone cap is indicated.

FIGURE A-4. North-South cross-section through the Vernon Field at the location of the State Vernon & Smock #13-23 HD well showing the probable extent of the shale-filled cavern within the Upper Dundee section and its relation to the dolomite and limestone facies typical of the field. The piercing points of the horizontal wells are indicated. The surface of the Dundee Formation is drawn and the position of the dense limestone cap is indicated. Nearby control wells are projected onto plane of cross section.

FIGURE B-1. Mission Road profile of microbial data. These data show higher values over the (known) extents of Vernon Field.

FIGURE B-2. Geochemical survey over Vernon Field for microbial data. The demonstration well is located at UTM coordinates 4847500 – 68000. The proposed extension well is sited at UTM coordinates 4847500 – 681500.

FIGURE 1. Location map showing Vernon Field and all oil fields in Michigan producing from hydrothermal dolomite reservoirs (“top porosity”).

FIGURE 2

FIGURE 3. Structure contour map on top of Dundee Formation in vicinity of Vernon Field.

FIGURE 4

VERNON FIELD - microbial data

FILE: All Microbial LatLong Smock Cutout

FIGURE A-2

ST. VERNON & SMOCK #13-23 HD1 WELLBORE SCHEMATIC

FIGURE A-3

FIGURE B-1. Profile of microbial data along Isabella Road, Isabella County.

FIGURE B-2. Contour map of microbial data collected over Vernon Field, summer 2000.