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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

DEMONSTRATION WELL AND SURFACE GEOCHEMISTRY AT VERNON FIELD

In budget period 1, the principal accomplishments were the drilling of the first demonstration well, the State Vernon & Smock 13-23 HD1 (permit number: PN 53945) in Vernon Township, Isabella County, Michigan and the launching of a surface geochemical sampling program to sample and analyze soil gases based on SPME (Solid Phase Micro Extraction) technology. An annual project review meeting was held in Tampa, FL March 1-5.

The Smock well was successfully drilled to a depth of 3157 feet by November 17, 2000. (3157 feet is the depth reported by the logger, the driller reported a depth of 3177 feet). Two laterals were required to locate a pay zone approximately 175 feet in length. However difficult reservoir conditions prevented putting the well in production and the well was shut in and abandoned January 15, 2001. A post mortem is underway to determine why the well was not economic. Preliminary indications are that the area did contain hydrocarbons, but the zone was flushed by earlier recovery operations. The geochemical survey was extended to the area East of the Smock and showed an exaggerated high to the Northeast. It also shows a significant high over the area proposed for a 2nd demonstration well.

A post mortem on the demonstration well so far indicates that the main reason it was uneconomic was because of the presence of shale plugs and drainage due to previous operations. It is possible that the later itself was faulty (e.g. "porposing" up and down so as to create water blockages). The well site is being used to calibrate the geochemical data. A postmortem report on the well, including the geology and geochemistry used to site the well, is presented in this report.. The geochemical results will be used to guide siting Phase 2. More geochemical surveys either have been conducted or are under way.

A number of unexpected geological results were uncovered by 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 form the soil horizon.

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. Also, the geochemical surveys should have been conducted on a tighter grid spacing and techniques based on direct detection of soil gases, such as headspace gases, should have been emphasized.

Future plans – At the Annual Meeting plans were made to write up the post mortem for the State Vernon-Smock #13-23 and focus on using the data obtained from the well to develop a geologic model for the field. Plans were also made to execute further geochemical surveys at Vernon Field and elsewhere. We would also like to focus the seismic task on the 3D seismic data set over Stoney Point Field (Michigan) rather than shooting new 2D seismic. Work is underway to develop a technique to sample and analyze C1 – C8 soil gases using SPME fiber technology.

EXECUTIVE SUMMARY

The geochemical sampling team collected additional 148 samples at Vernon Field along 5 new traverses. Most of the locations were sampled for three types of analyses: microbial, iodine and enzyme leach; no results from the second batch of samples were available in time for this report.

In addition to the sampling, a study was begun on the feasibility of collecting and analyzing hydrocarbon gases (C1 – C8) directly. Although several companies offer these services, the cost ($200-300/sample w/o sampling fee) is high, on par with the cost of a 3D seismic survey, and may not include the raw data. However direct sampling of reservoir gases collecting in the soil appear to offer the best approach and should be included in this study. It would probably work well at Vernon Field. It may be possible to lower costs considerably; initial estimates of $20/sample for GCMS (Gas Chromatography – mass spectrometry) analysis are attractive and might induce to Michigan producers to include soil surveys in their routine field work-ups.

A complete set of digital data was assembled for Vernon Field and nearby locations. The set consists of well locations, formation top picks, lithologies and scanned images of driller's reports and scout tickets. Well logs are still being located.

The annual meeting for the Class Revisit work group is tentatively scheduled for the week of March 1-7 in Tampa, Fl. By that time all of the geochemical data will be available and final decisions regarding drilling can be made.

CHAPTER 1. INTRODUCTION

Project Description

In this project a consortium consisting of Cronus Exploration (Traverse City, MI), Michigan Technological University (Houghton, MI) and Western Michigan University (Kalamazoo, MI) proposes to develop and execute an economical and environmentally sensitive plan for recovery of hydrocarbons from an abandoned shallow-shelf carbonate field that is typical of many fields in the U. S. Midwest. This is a 5-year project that will use surface geochemistry as a tool to reduce risk in locating and producing hydrocarbons in Class II fields.

The project will develop new techniques for measuring hydrocarbon gases in the soil horizon to locate new and bypassed oil in the shallow-shelf carbonate environments typified by the Dundee and Trenton Formations of the Michigan Basin (Fisher et. al., 1988). In Phase I of the project, the consortium proposes to re-develop the Vernon Oil Field located in Vernon Twp. (T16N-4RW), Isabella County, Michigan (Figure 1) and produce both bypassed hydrocarbons from the original field (Figure 2) and to locate and produce extensions of the original field.

The producibility problems are (1) locating remaining oil, (2) characterizing the reservoir architecture (e.g. structure, alteration and facies distribution), and (3) efficiently draining remaining hydrocarbons. Preliminary cost analysis showed that 3D seismic is too expensive for this type of project (the cost is comparable to the entire drilling operation), yet the present or absence of hydrocarbons needs to be better known prior to drilling. Recent advances in surface geochemistry suggest that this technology is ready for application in recovery operations. It is cheap relative to seismic but needs refinement. Fortunately new sampling technologies such as SPME (Site Specific Micro Extraction) fiber sampling) and new instrumentation (GCMS – Gas Chromatograph-Mass Spec) suggest that direct sampling and identification of hydrocarbons released from the reservoir to the soil is possible. 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. Studies have shown that this is feasible under some conditions (Schumacher , Hitzman, Tucker and Roundtree, 1997); the problem is to find the best techniques and methodologies for this set of reservoir conditions.

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 several analog fields and active 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.

Regional Geology of Vernon Field

In Phase I attention was focussed on Vernon Field in Isabella County, Michigan (Figure 1). Vernon Field is one of the earliest oil and gas developments in the Michigan Basin, dating back to 1930 (Upp, 1969; Howell and van der Pluijm, 1990). The field predates all other Dundee discoveries in the state except for Port Huron, Muskegon and Mt. Pleasant. Vernon has a total production 5,000,000 barrels of oil from the 78 original wells with an average recovery per acre drilled of 5,700 barrels. Vernon Field lies just North of Rosebush Field, another prolific Dundee producer. Rosebush is located on a separate anticline and produces from a different horizon in the Lucas Formation. The producing zone in Vernon is the upper Dundee 'Rogers City' Member. The reservoir rock type is secondary dolomite that characteristically has good porosity and permeability with abundant vugs and fractures (Harrison, 1992a, 1992 b).

On a regional scale, the field is located on a slight structural high near a dominant syncline. The –2900 contour on the top of the Dundee Formation completely encloses Rosebush Field, but Vernon Field lies to the NW on the nose of a plunging anticline about 20-30 feet lower extending toward the basin (Figure 2). There are only small areas of structural closure at Vernon and the hydrocarbon accumulation cannot be due sole to structural trapping; the oil pool is primarily the result of an updip permeability barrier type stratigraphic trap. The southern updip lateral seal for the reservoir dolomite is impervious limestone. Figure 3 is a contour map of the "top of porosity" over Vernon and Rosebush Fields. This coincides with the nearly 100% altered (dolomitized) rock.

Vernon Dundee Prospect

The Vernon Field located in Vernon Township (T16N-4RW), Isabella Co., Michigan, is one of the earliest oil and gas developments in the Michigan Basin, dating back to 1930. The field predates all other Dundee discoveries in the state except for Port Huron, Muskegon and Mt. Pleasant. Vernon totaled 5,000,000 barrels of oil from the 78 original wells. The average recovery per acre drilled is 5,700 barrels. The reservoir is maintained by a strong bottom water drive. The original oil-water contact for the field is projected at a subsea depth of -2950. Maximum gross pay thickness was 55 feet. All holes target the uppermost dolomite porosity at the top of the Dundee.

Justification for Selecting the Stough #1A-23 HD

The Stough #1A-23 HD drilling unit was drilled in Phase I of this project. It is described as the SW¼ SE¼ of section 23 and the NW ¼ of the NE¼ of section 26, Vernon Township, Isabella Co. Although the prospect proved to be an economic failure, it did provide mixed geochemical signals and further surface geochemistry is scheduled for this area (see below). . The surface geochemistry involved in this well is described in Chapter 2 of this report and the drilling results are fully described in Chapter 3.

The original rational for selecting this area is as follows. Attic oil reserves were the objective of the prospect. The Cronus prospect is situated on the most prolific lease in the Vernon field. Developed in 1933, the Stough farm was a lay down 80 acres tract with 5 oil wells on it. Cumulative production for the lease is 1,000,000 barrels oil or 200,000 barrels per well. This amounts to a recovery per acre of 12,500 barrels. These outstanding recovery numbers are to be expected as the lease is favorably positioned near the updip margin of the reservoir dolomite facies. The average gross pay thickness for the 5 wells was 40 feet with several of the individual producers having as much as 55 feet of pay. The recoveries also indicate the reservoir quality is superior in this area.

The Stough #1A-23 HD also stands to benefit from oil reserves left behind by the original wells. Relatively recent infill drilling in Vernon indicates the reservoir holds bypassed oil as the old producers were damaged by water coning and/or faulty drilling procedures.

A successful re-entry/sidetrack of an old hole sparked interest in Vernon, which resulted in 16 holes being drilled in and around the field during a four year period from 1981 to 1985. Central Michigan Exploration re-entered and sidetracked the Bigelow-Stephens #1 (P.N. 1301) in March of 1981. The well is located in the NW¼ NW¼ SE¼ of section 22. Completed in 1933, the original hole was drilled 57 feet below the top of the Dundee and into the water. The well was plugged 45 days after reaching total depth. Upon topping the Dundee with the sidetrack, the new hole took off flowing at a rate of 200 BOD natural. The well maintained a flow rate of 100 BOD with no water for the first year of operation. Since the end of 1982, mechanical problems have hindered production. Estimated cumulative total for the Bigelow-Stephens #1 is 50,000 barrels of oil.

Of the new 16 wells drilled during the early 1980's, 7 were located in the interior of the field. However, all 7 were disadvantaged by being located 165 feet or less from an old plugged producer. Ideally, the new holes would have been spotted at undeveloped sites on the 49 acre units. Despite this drawback, 6 of the 7 wells proved to be semi-commercial for local operators. Initial production averages were 25 BOD with 100 BWD. Per well cumulative totals are approximately 30,000 barrels of oil. Although the oil recoveries achieved by the infill wells are rather modest, the numbers are considered important because they demonstrate the Vernon reservoir contains oil reserves bypassed by the original development.

One of the Vernon infill wells was the Stough #1A-23 (NW¼ SW¼ SE¼, 23) drilled by Summit Petroleum in 1982. The up hole portion of this well bore will be utilized in the drilling operations for the proposed horizontal well. The Stough #1A-23 is located 130 feet south of an old, plugged producer. Originally planned as a deeper Richfield test, the well encountered severe lost circulation zones in the middle Dundee and as a result drilling had to be halted at the base of the horizon. Open hole wireline logs and a mud log are available from this test. The neutron porosity log indicates the upper Dundee lithology is dolomite with estimated porosity ranging between 5% and 12%. The resistivity logs exhibit 32 feet of gross pay section with a maximum water saturation of 30%. The logs also display a water contact at a depth of -2937 subsea. The drill cuttings from the top of the Dundee are described as porous dolomite with 100% fluorescence and streaming cut. A good gas show was measured across the upper 25 feet of the Dundee by the gas detector.

The Stough #1A-23 was completed for 18 BOD with 100 BWD. Cumulative oil production is approximately 30,000 barrels. Based on the optimistic log and sample data from the well, these production numbers are disappointing. However, the completion of the well may have been undermined by a poor cement job. The cavernous porosity in the middle Dundee made a quality cement job difficult. The bond log from the well indicates the top of cement is at 3670', only 40' above the Dundee pay zone. In conclusion, although the Stough #A1-23 proved to be a marginal producer, the encouraging log and sample data suggests the reservoir contains significant bypassed oil in the prospect area.

A lateral hole was though to be an excellent method to evaluate this prospect. One advantage the horizontal well bore offers is that it allows the well to be produced at a higher rate without significantly reducing the bottom hole flowing pressure. This minimizes the chance of water coning thereby delaying water production. Where a conventional well can be produced at 50 BOD, a horizontal well can be produced at 100 BOD. This reduces payout time and increases return on investment.

The horizontal well path was orientated south form the Stough #1A-23 surface hole. The objective of the horizontal well is to follow the upper reservoir dolomite updip until it pinches out. The lateral hole is projected to start out at a TVD of -2905 subsea. Anticipated length of the lateral section is 1000 feet.

East Vernon Dundee Prospect

White #1-24 HD

As a follow-up to the Stough well, the White #1-24 HD 80 acre unit (SW ¼ SW ¼ of section 24 and the NW ¼ NW ¼ of section 25 of Vernon Twp.) is proposed to evaluate a 200 acre undeveloped prospect area adjoining the Vernon field to the east. 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 ½ 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 White #1-24 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 (SE¼ SE¼, 23). Drilled in 1933, the 40 acre tract cumulated 132,558 barrels before abandonment in 1938. The Verette #1 (NW¼ SE¼ SE¼, 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 White #1-24 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 (see maps and logs). 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 White #1-24 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 White #1-24 HD test, recoverable oil reserves are estimated upwards to 350,000 barrels.

CHAPTER 2. THE DEMONSTRATION WELL

Introduction

As part of the scheduled deliverables for this project, a demonstration well (the State Vernon & Smock #13-23 HD1) was designed and permitted in Vernon Field, Isabella County, Michigan. The object of the well was to test the ability of horizontal drilling technology to locate and produce reserves indicated by a surface geochemical survey (see Chapter 2). 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. It is widely believed in Michigan that this contact represents an ancient erosion surface developed on karst. Given that the pay zones are usually only 10-15 feet thick, it is necessary to probe close to the contact without entering the bottom water and avoiding the overlying shale. The difficulty is measurably increased by the tendency to encounter shale "plugs" at the contact, which may be mud-filled sinkholes several 100 feet deep and 50-100 feet in diameter.

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 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 3). 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 4).

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 5. 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 5 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 5) 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 4) and to the NE (Figure 3). 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 5) 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.

Geology near 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 5 and 6 are two such cross-sections. Figure 5 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 2,3 and 4. Figure 6 is a North-South cross-section taken along the line of section indicated in Figure 4. Note that the vertical scale is approximately the same in both cross-sections but the horizontal scale is smaller in Figure 6 than in Figure 5 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 6). 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 its 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 4.

CHAPTER 3. 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. (Details on the results of the surface iodine, enzyme leach results can be found elsewhere.)

The microbial Mission Road profile is shown in Figure 8. Samples were collected at 200meter (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 8). 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 ½ 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 9. 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 filed 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 weak high over the demonstration well, but statistical analysis suggests that this should be regarded as a marginal anomaly if at all. Data collected to date over the site of the second proposed well, the Bowers #1-26 in the East Vernon Prospect (Figures 2-4) are inconclusive but still favorable.

CHAPTER 4. CONCLUSIONS

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 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?) may be able 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. Postmortem activities will focus on rectifying both of these deficiencies.

What did we learn?

The most important lesson from this well was that we must pay more attention to the geochemical data, particularly the soil-gas data. 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 but 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.

Future Work

Geochemical sampling will be continued this spring through the fall at Vernon. The drill site will be resampled at a tighter grid spacing (50 m?) and soil-gas samples will be collected in addition to the others. A new surface geochemical technique, SPME fiber technology, which directly samples soil gas will be tested and evaluated.

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. 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 4. 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 5. 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 6. 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 7. Grayscale contour map of the top of the Dundee Formation near Vernon Field. Other fields shown are Rosebush, Leaton, Wise, and Isabella.

FIGURE 8. Mission Road profile of microbial data. These data show higher values over the (known) extents of Vernon Field.

Figure 9. 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.

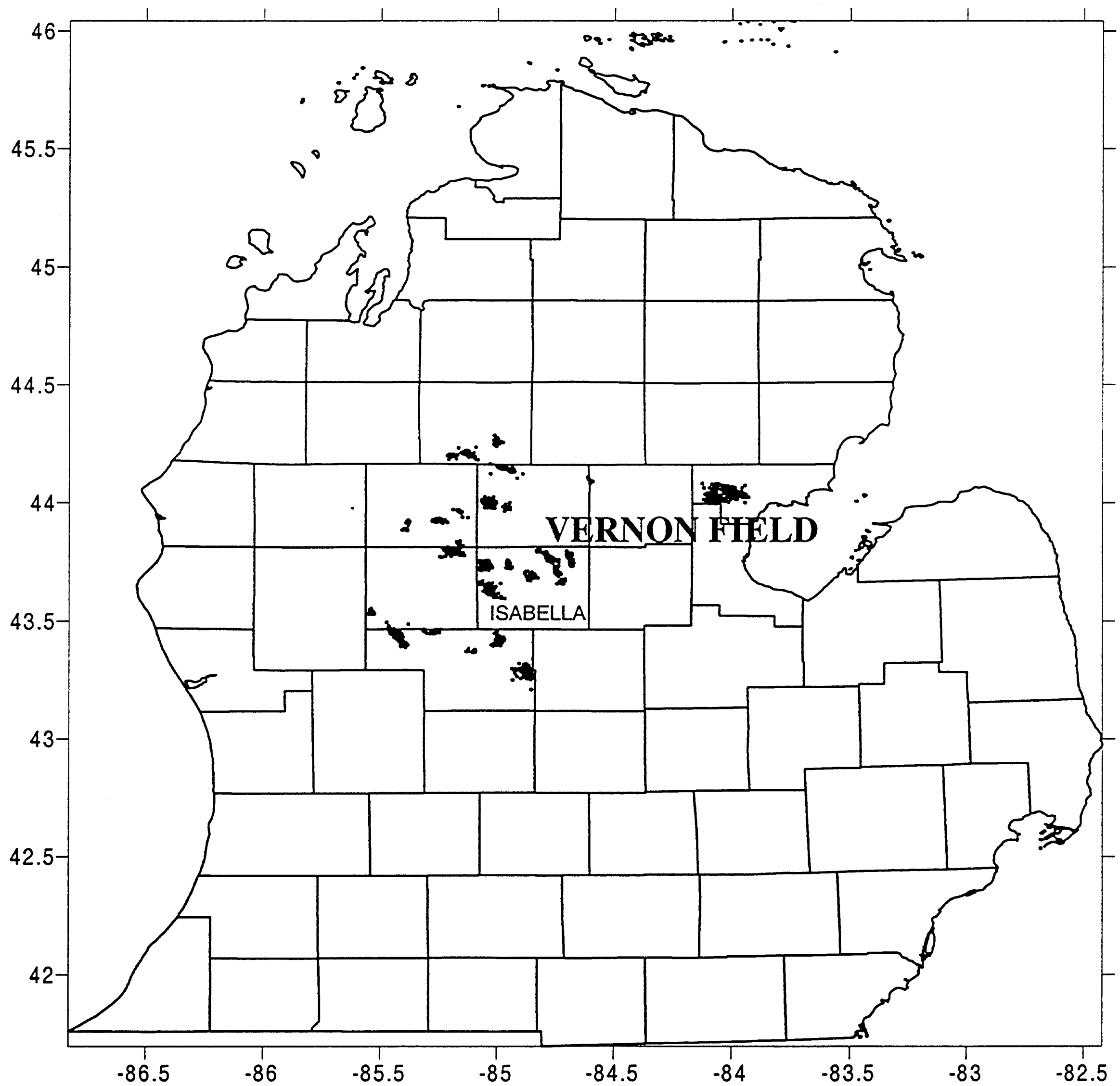


FIGURE 1. Location map showing Vernon Field and all oil fields in Michigan producing from hydrothermal dolomite reservoirs ("top porosity").

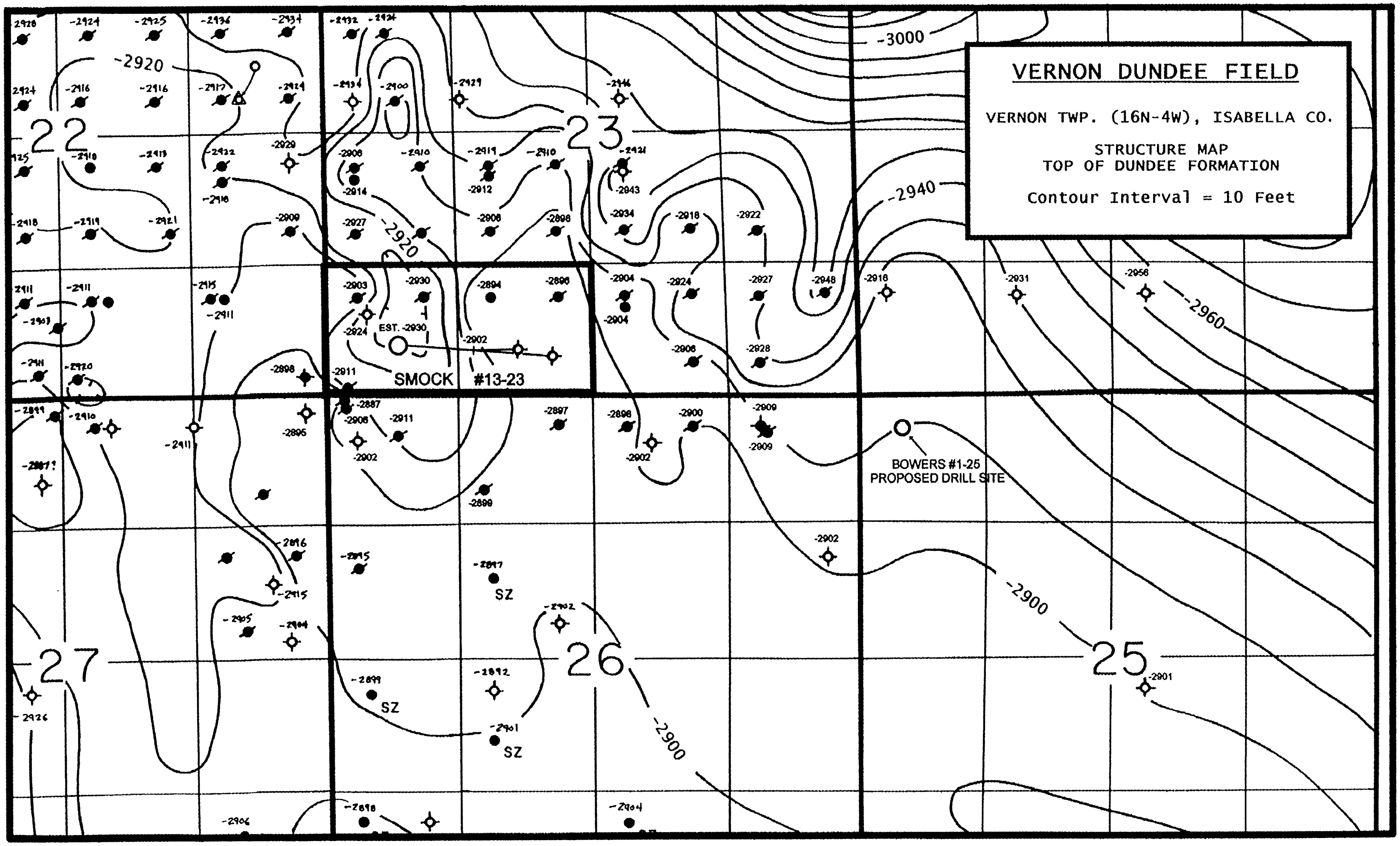
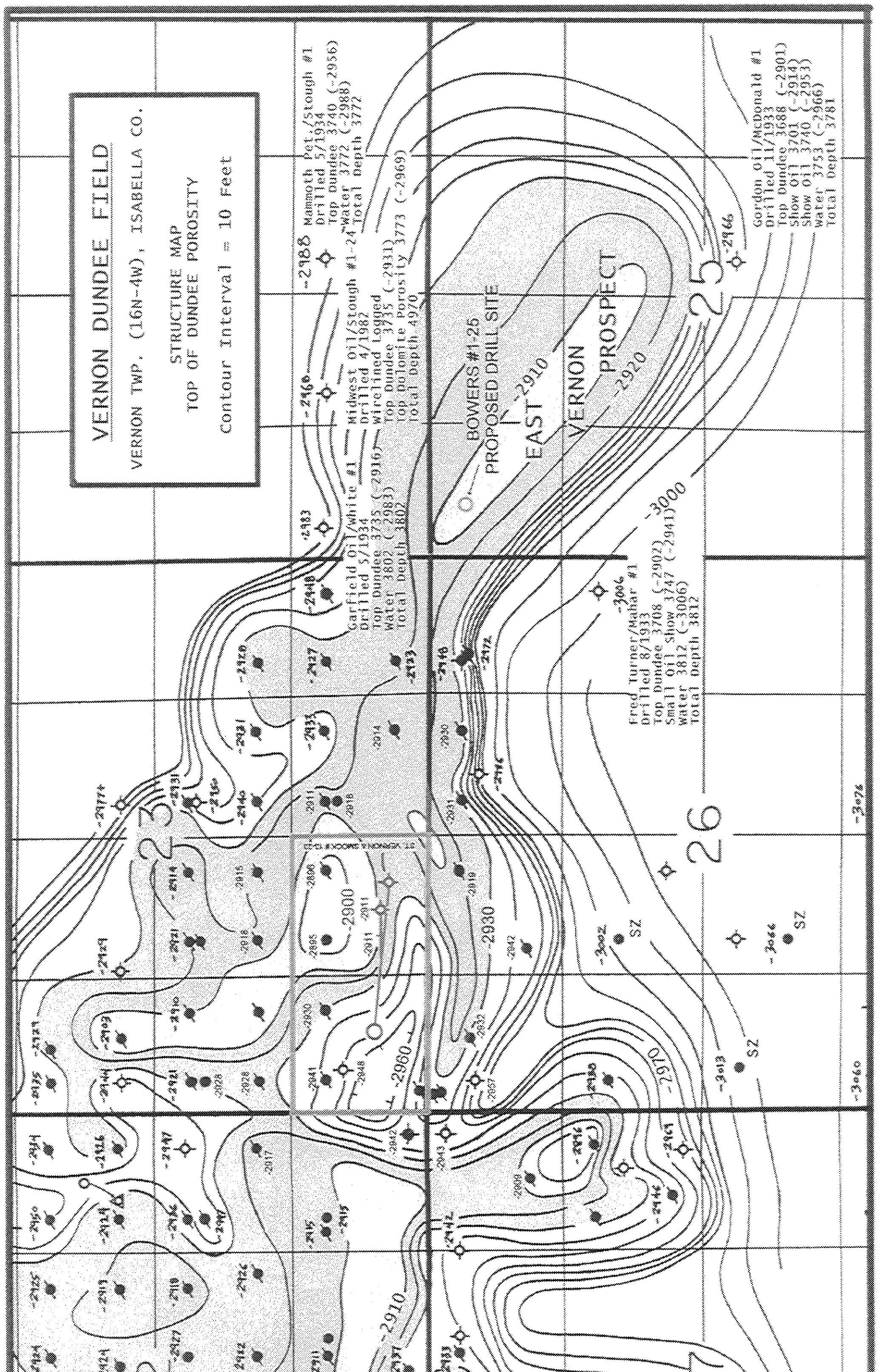

VERNON DUNDEE FIELD
VERNON TWP. (16N-4W), ISABELLA CO.
STRUCTURE MAP
TOP OF DUNDEE FORMATION
Contour Interval = 10 Feet
BOWERS #1-25
PROPOSED DRILL SITE
SMOCK #13-23
EST. -2930
-3000
-2960
-2940
-2920
-2900
22
23
25
26
27
SZ

FIGURE 2



VERNON DUNDEE FIELD
VERNON TWP. (16N-4W), ISABELLA CO.
STRUCTURE MAP
TOP OF DUNDEE POROSITY
Contour Interval = 10 Feet
Mammoth Pet./Stough #1
Drilled 5/1934
Top Dundee 3740 (-2956)
Water 3772 (-2988)
Total Depth 3772
Midwest Oil/Stough #1-24
Drilled 4/1982
Wirelined Logged
Top Dundee 3735 (-2931)
Top Dolomite Porosity 3773 (-2969)
Total Depth 4970
Garfield Oil/White #1
Drilled 5/1934
Top Dundee 3735 (-2916)
Water 3802 (-2983)
Total Depth 3802
Gordon Oil/McDonald #1
Drilled 11/1933
Top Dundee 3688 (-2901)
Show Oil 3701 (-2914)
Show Oil 3740 (-2953)
Water 3753 (-2966)
Total Depth 3781
Fred Turner/Mahar #1
Drilled 8/1933
Top Dundee 3708 (-2902)
Small Oil Show 3747 (-2941)
Water 3812 (-3006)
Total Depth 3812
BOWERS #1-25
PROPOSED DRILL SITE
EAST
VERNON
PROSPECT
22
23
25
26
27

FIGURE 3

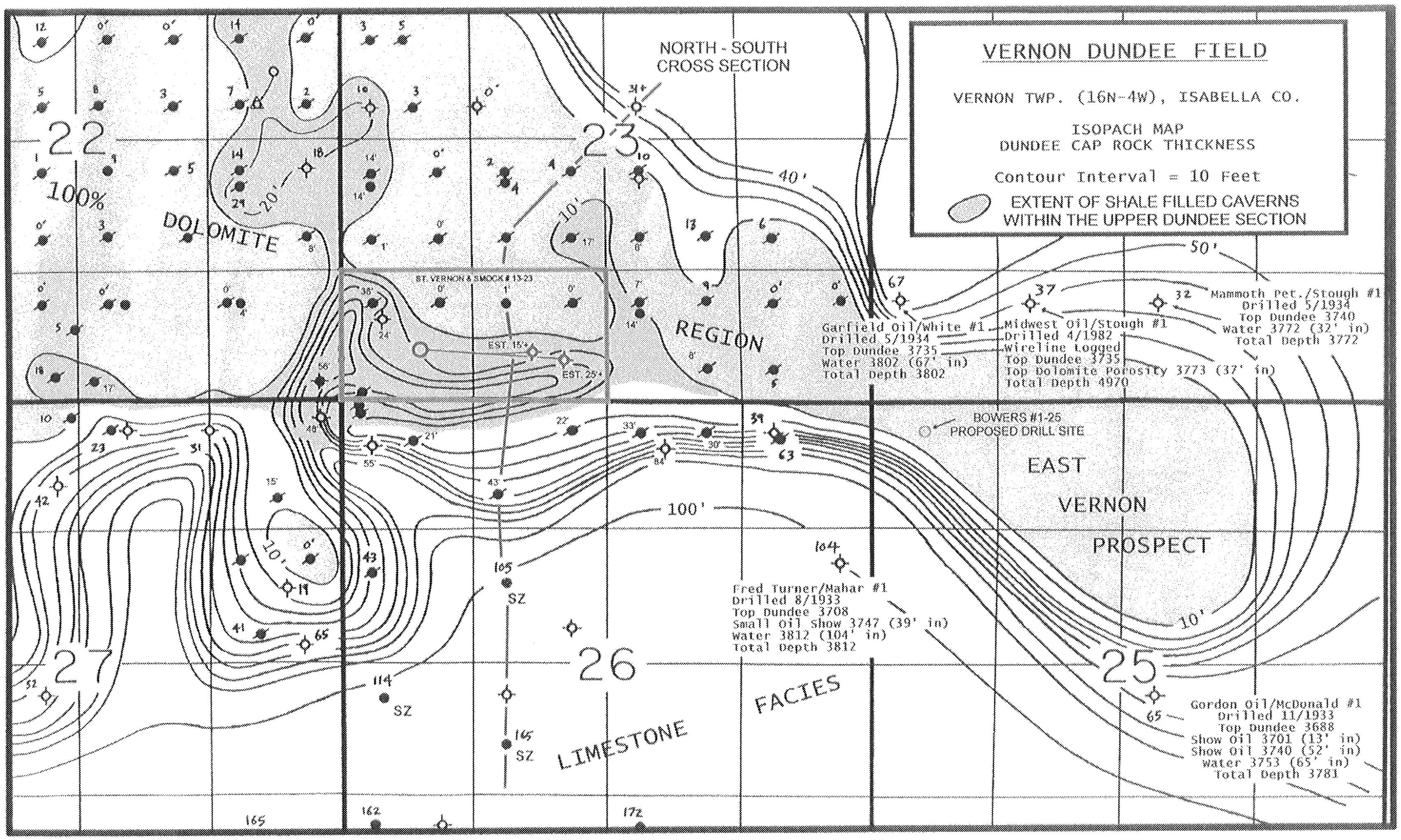
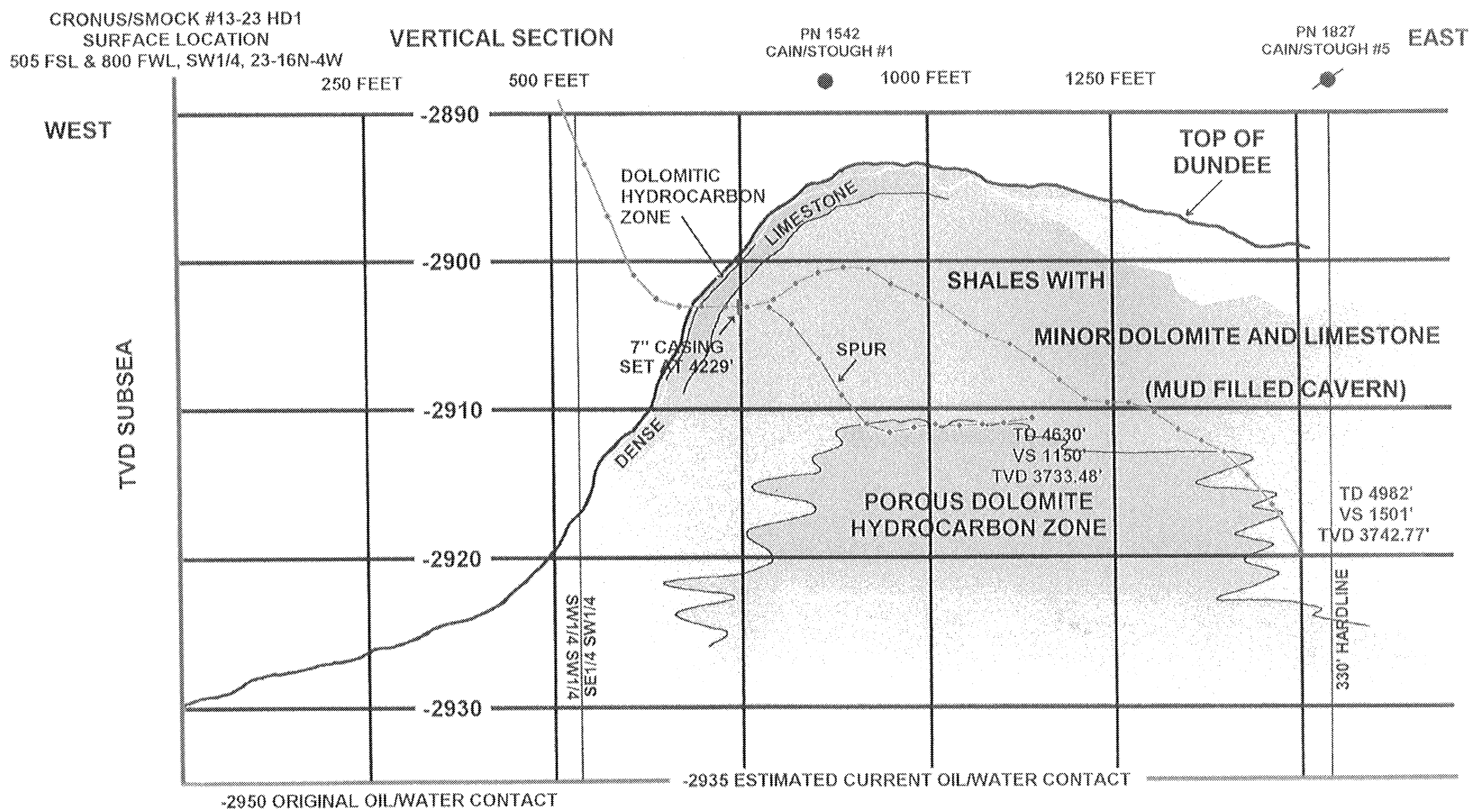

VERNON DUNDEE FIELD
VERNON TWP. (16N-4W), ISABELLA CO.
ISOPACH MAP
DUNDEE CAP ROCK THICKNESS
Contour Interval = 10 Feet
EXTENT OF SHALE FILLED CAVERNS WITHIN THE UPPER DUNDEE SECTION
NORTH - SOUTH CROSS SECTION
22
23
26
25
27
100%
DOLOMITE
REGION
LIMESTONE
FACIES
EAST
VERNON
PROSPECT
ST. VERNON & SMOCK # 13-23
BOWERS #1-25
PROPOSED DRILL SITE
Garfield Oil/White #1
Drilled 5/1934
Top Dundee 3735
Water 3802 (67' in)
Total Depth 3802
Midwest Oil/Stough #1
Drilled 4/1982
Wireline Logged
Top Dundee 3735
Top Dolomite Porosity 3773 (37' in)
Total Depth 4970
Mammoth Pet./Stough #1
Drilled 5/1934
Top Dundee 3740
Water 3772 (32' in)
Total Depth 3772
Fred Turner/Mahar #1
Drilled 8/1933
Top Dundee 3708
Small Oil Show 3747 (39' in)
Water 3812 (104' in)
Total Depth 3812
Gordon Oil/McDonald #1
Drilled 11/1933
Top Dundee 3688
Show Oil 3701 (13' in)
Show Oil 3740 (52' in)
Water 3753 (65' in)
Total Depth 3781
100'
50'
40'
20'
10'

FIGURE 4



VERNON FIELD

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

FIGURE 5

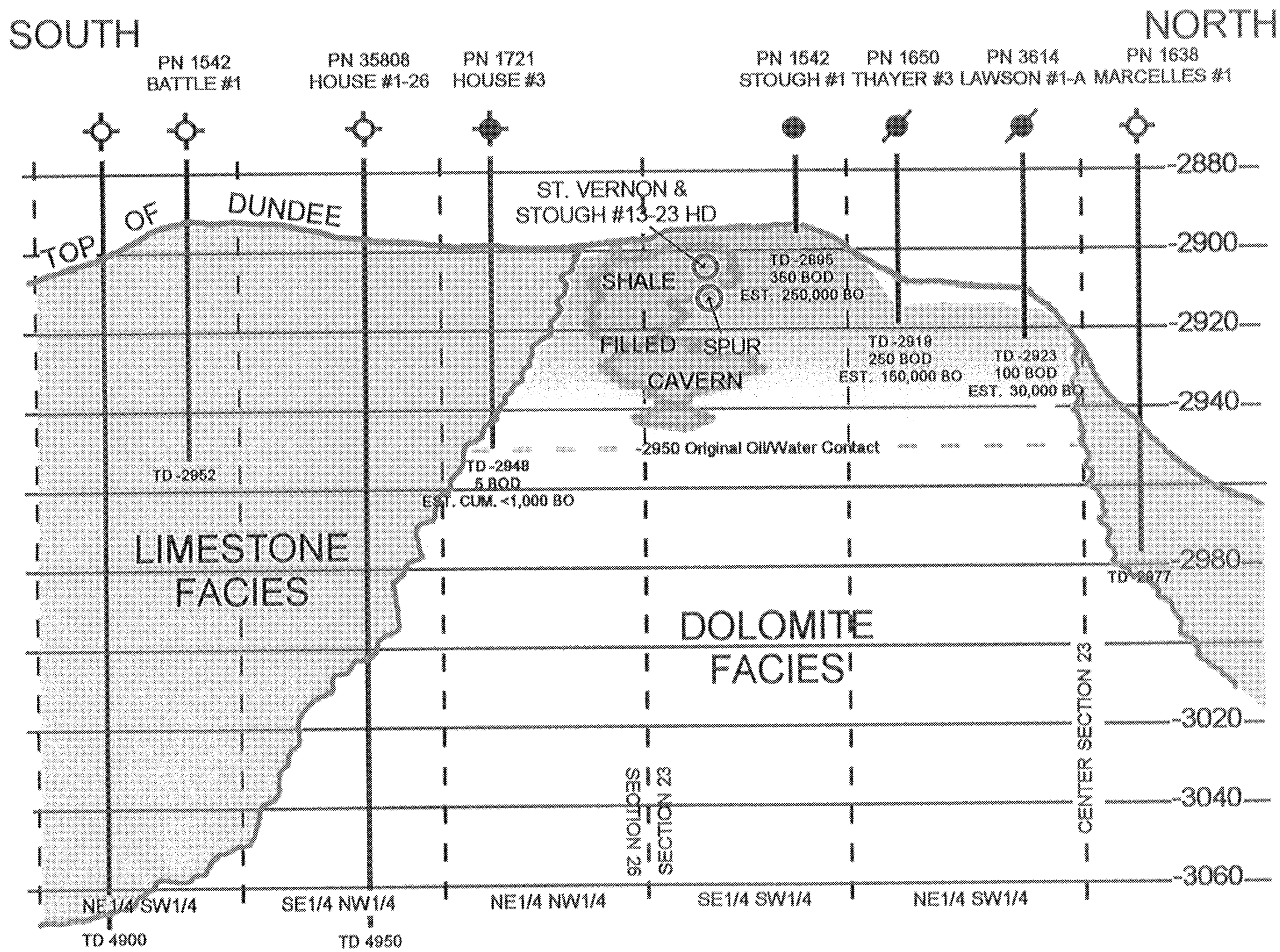

SOUTH
NORTH
PN 1542
BATTLE #1
PN 35808
HOUSE #1-26
PN 1721
HOUSE #3
PN 1542
STOUGH #1
PN 1650
THAYER #3
PN 3614
LAWSON #1-A
PN 1638
MARCELLES #1
TOP OF DUNDEE
ST. VERNON &
STOUGH #13-23 HD
SHALE
FILLED
CAVERN
SPUR
TD -2895
350 BOD
EST. 250,000 BO
TD -2919
250 BOD
EST. 150,000 BO
TD -2923
100 BOD
EST. 30,000 BO
-2950 Original Oil/Water Contact
TD -2948
5 BOD
EST. CUM. <1,000 BO
TD -2952
TD -2977
LIMESTONE
FACIES
DOLOMITE
FACIES
-2880
-2900
-2920
-2940
-2980
-3020
-3040
-3060
SECTION 26
SECTION 23
CENTER SECTION 23
NE1/4 SW1/4
SE1/4 NW1/4
NE1/4 NW1/4
SE1/4 SW1/4
NE1/4 SW1/4
TD 4900
TD 4950

FIGURE 6

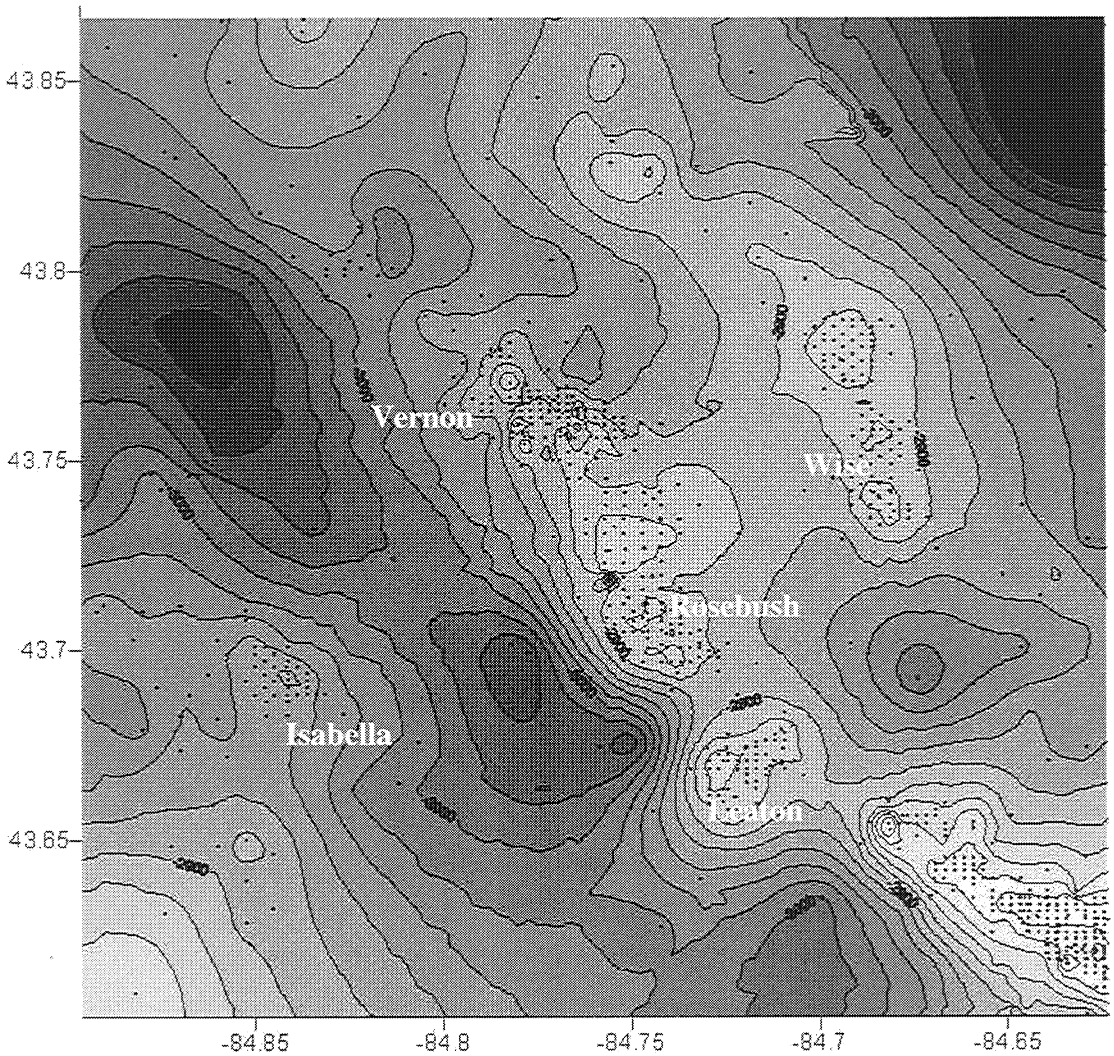


FIGURE 7. Structure contour map on top of Dundee Formation in vicinity of Vernon Field.

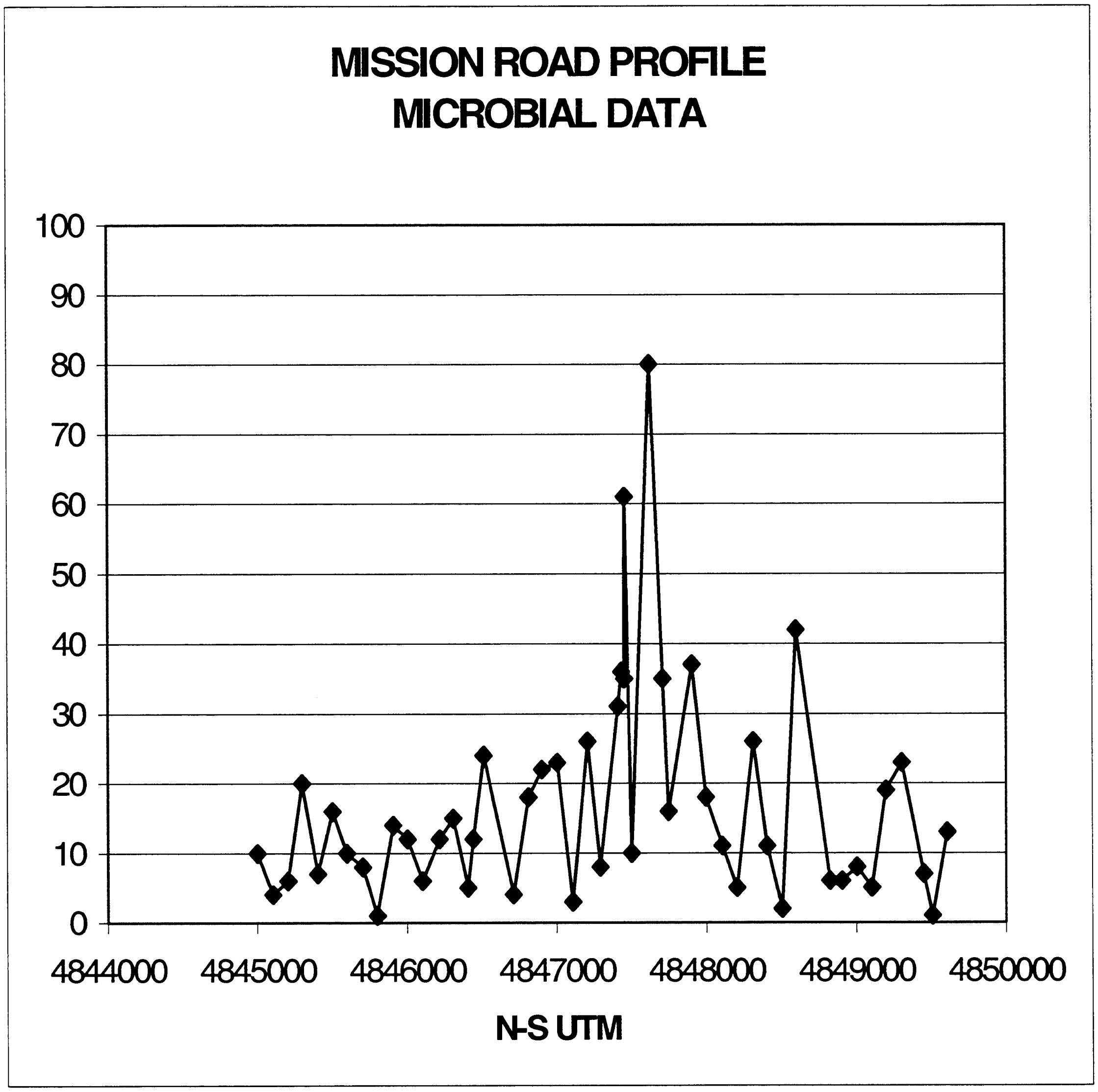


FIGURE 8. Profile of microbial data along Isabella Road, Isabella County.

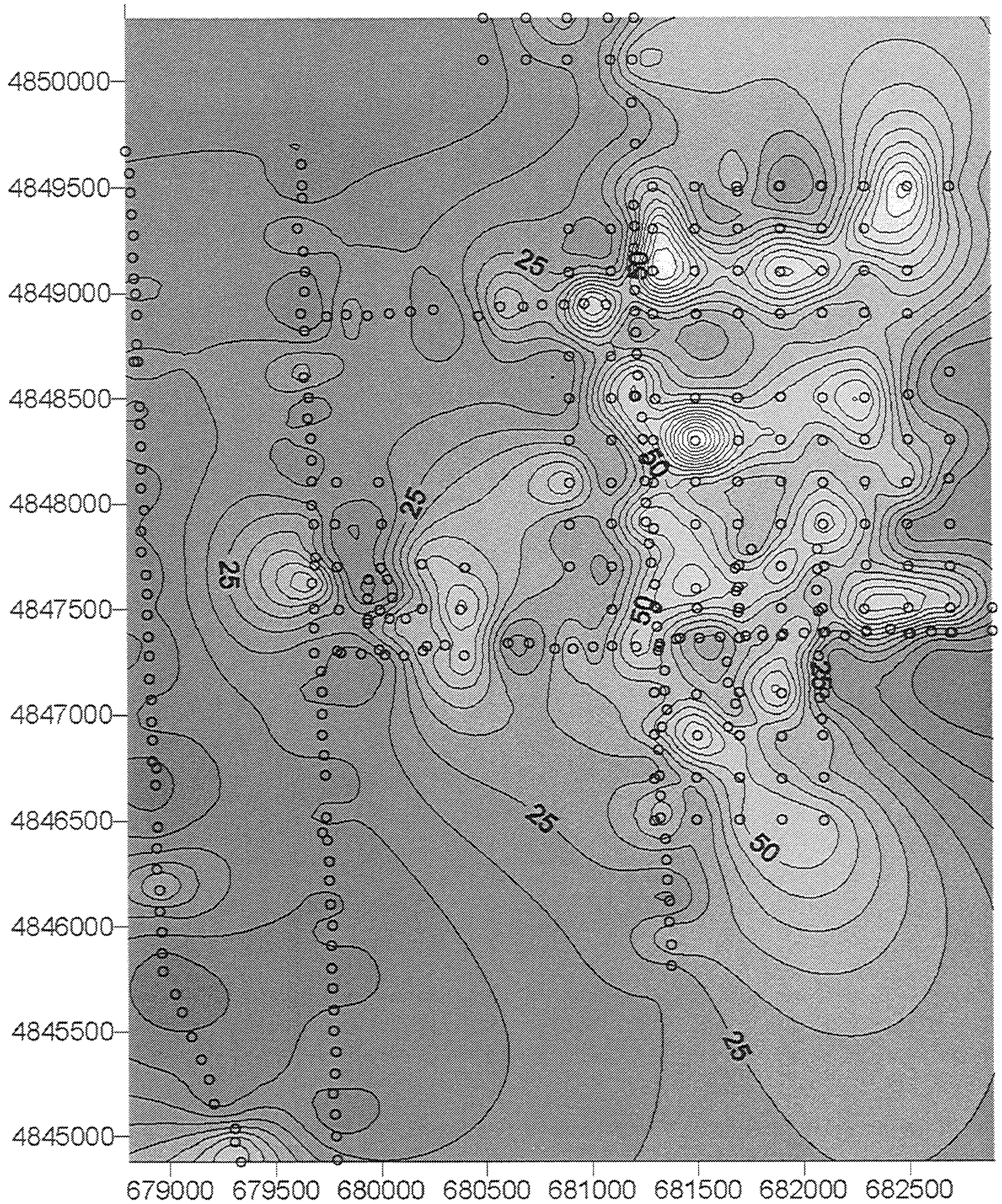


FIGURE 9. Contour map of microbial data collected over Vernon Field, summer 2000.