

June 5, 2002

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National Energy Technology Center  
U.S. Department of Energy  
P.O. Box 10940  
Pittsburgh, PA 15236

RE: Annual Technical Progress Report for DE-AC26-00BC15122 for period ending March 20, 2002

Enclosed is the Annual Technical Progress Report for the period ending March 20, 2002 for the project titled USING RECENT ADVANCES IN 2D SEISMIC TECHNOLOGY AND SURFACE GEOCHEMISTRY TO ECONOMICALLY REDEVELOP A SHALLOW SHELF CARBONATE RESERVOIR: VERNON FIELD, ISABELLA COUNTY, MI. The DOE project number is DE-AC26-00BC15122, and the reporting period is from March 21, 2001 through March 20, 2002. This submission contains 1 hardcopy and 1 electronic copy on a CD-ROM.

Please contact me at (906) 487-2894, or email [jrw@mtu.edu](mailto:jrw@mtu.edu), or contact Carol J. Asiala at (906) 487-2033 or email [cjasiala@mtu.edu](mailto:cjasiala@mtu.edu) with any questions.

Sincerely,

James R. Wood  
Professor

att: Annual Report  
F510.1-5 Request for Patent Clearance Form

cc: A. Quinn, MTU #990520

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

**TYPE OF REPORT: ANNUAL**

**REPORTING PERIOD START DATE: March 21, 2001**

**REPORTING PERIOD END DATE: MARCH 20, 2002**

**PRINCIPAL AUTHORS:**

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**DATE REPORT WAS ISSUED: APRIL, 2002**

**DOE AWARD NUMBER: DE-AC26-00BC15122**

**NAME AND ADDRESS OF SUBMITTING ORGANIZATION:**

**MICHIGAN TECHNOLOGICAL UNIVERSITY  
1400 TOWNSEND DRIVE  
HOUGHTON, MI. 49931**

## **ABSTRACT**

The fault study continues to find more faults and develop new techniques to visualize them. Data from the Dundee Formation has been used to document 11 major faults in the Michigan Basin which have now been verified using data from other horizons. These faults control the locations of many of the large anticlinal structures in the Michigan Basin and likely controlled fluid movements as well. The surface geochemistry program is also moving along well with emphasis on measuring samples collected last sampling season. The new GC laboratory is now functional and has been fully staffed as of December. The annual project review was held March 7-9 in Tampa, Florida. Contracts are being prepared for drilling the Bower's prospects in Isabella County, Michigan, this spring or summer. A request was made to extend the scope of the project to include the Willison Basin. A demonstration well has been suggested in Burke County, N. Dakota, following a review of 2D seismic and surface geochem. A 3D seismic survey is scheduled for the prospect.

### **Results**

The main results of this project are delineation of major faults in the Central Michigan Basin, and the geochemical calibration of several fields. These additional faults will be used to construct a structural and fluid flow model of the Michigan Basin. Geochemical surveys planned for 2002 will include traverses across the major branches of the fault system. We will concentrate on developing targets near the faults.

### **New Findings/Unexpected Results**

The discovery and delineation of the new fault pattern in the Central Michigan Basin continues to be the major new finding in this study.

### **Potential Applications**

New drilling prospects are being evaluated in relation to their proximity to the major faults. Geochemical surveys are being planned to cross the major faults to test the hypothesis that they are fluid conduits and leak hydrocarbons more readily.

### **Did data support project as expected or not?**

So far the new fault data supports the project mission of locating bypassed oil in shallow shelf carbonates. The Dundee Formation is an even more attractive target now that basin-scale fault maps are available. The fault locations are being refined as more horizons are processed.

### **Future Work**

Cross sections need to be constructed using the fault data and lithologic data needs to be acquired and incorporated into the cross-sections.

### **Should something else have been done?**

If we had known going into this project that re-working the existing formation tops data would yield such a detailed picture of the Central Basin structure, we might have focussed on that earlier in the project.

### **Lessons Learned**

Several lessons were learned, possibly foremost being that the old drilling records are still a valuable source of data. Future plans - We intend to keep pursuing this new direction, refining and filling in the basin model as well as using it to suggest areas that possible targets for surface geochemistry surveys.

## **DISCLAIMER**

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe on any privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation or favoring by the United States Government nor any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government.

## **LIST OF GRAPHICAL MATERIALS**

Figure 1. Generalized stratigraphic column for Michigan Basin.

Figure 2. Index map showing major faults in the Central Michigan Basin.

Figure 3. Location Map of Microbial Samples.

Figure 4. Lithologic Cross-Section across Central Michigan Basin.

Figure 5a. Contour Map on top of Dundee Formation for Vernon-Rosebush Fields. No faults.

Figure 5b. Contour Map on top of Dundee Formation for Vernon-Rosebush Fields with fault.

Figure 6. Index map showing locations of Michigan and Williston Basins.

Figure 7. Generalized stratigraphic column for Williston Basin.

Figure 8. Location map for Myrtle Beach Prospect, N. Dakota.

Figure 9. Location Map of Microbial Samples at Myrtle Beach Prospect, Burke County, N. Dakota.

## EXECUTIVE SUMMARY

Work has progressed on delineation of the basin-scale faults in the center of the Michigan Basin reported last time. Faults have been identified and traced using data from six horizons in addition to the Dundee Formation. Presentations of this new data was made in the annual Tampa meeting in March and at a monthly SPE (Society of Petroleum Engineers) in Traverse City, Michigan, in May. Good feedback was obtained at both sessions and has improved and clarified the original interpretations. An abstract on the topic was submitted for the regional Eastern meeting of the AAPG this fall in Champaign, Illinois.

A request was made to DOE to extend the drilling demonstrations to the Williston Basin following presentations and discussions at the March Tampa meeting. Preliminary approval has been received to do this and formal approval is expected in June or July of this year. In anticipation of this approval work has begun gathering relevant data and materials as well as running preliminary geochemical survey over one prospect, Myrtle Beach, in Burke County, N. Dakota. Samples were collected for (1) microbial, (2) adsorbed gases and (3) iodine measurements.

The demonstration well for the Vernon extension in Clare County, Michigan is still being processed and hopefully will be on line this summer. More investors are needed, but the prognosis is good that this well will be drilled soon. The geochem study at the pinnacle reef complex in Manistee County, Michigan is continuing with good results but it is not clear if a demonstration well will be drilled due to problems concerning the amount of potential pay. Surface geochem indicates presence of hydrocarbons and seismic shows structures present, but the projected pay column does not meet the minimal conditions for a test. However, this prospect is still being evaluated.

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## **TECHNICAL REPORT**

The main goal of Budget Phase II is to develop and apply a new exploration and development strategy for intracratonic basins using the Michigan Basin as a model. In addition to the Michigan Basin, the Illinois and Williston Basins (Figure 6) in North America are cratonic basins that can be expected to have similar features. We also need to identify between 3-5 sites for new demonstration wells

This project enters Budget Phase II with two major accomplishments from Phase I. One is the successful launching of the surface geochemistry program, which collected over 800 samples from the site of the 1<sup>st</sup> demonstration well in Vernon Field. The second is the recent mapping of the Central Michigan Basin that has resulted in identifying a number of major faults that control the location of many of the reservoirs in the Michigan Basin as well as fluid movements. These faults were located from a combination of structure and surface relief maps obtained by girding the surface data for major stratigraphic horizons in the Michigan Basin (Figure 1), particularly the Dundee Formation, using top picks from databases previously compiled. Faults were inferred where the contour lines were most dense ("stacked") as well as from the prominent lineations displayed in the surface relief maps.

The first demonstration well for this project was drilled in December 2001 in the Vernon Field. A second demonstration well, the Bowers #1, is tentatively scheduled in Vernon Field for summer of 2002. A permit has been drawn from the State of Michigan and the surface site has been surveyed. Sites for subsequent wells are being studied in Manistee, Osceola and Livingston Counties. Surface geochemical data is being collected from these sites to complement geologic and geophysical studies.

A demonstration well is planned in Burke County, N. Dakota for the summer of 2002. This well will target the shallow-shelf carbonates in Paleozoic section of the Williston Basin, specifically the Devonian Winnipegosis Formation (Figure 7). Surface geochemical surveys and 3D seismic are scheduled to precede the drilling.

## **RESULTS**

A significant geological result was delineation of a number of major faults in the Central Michigan Basin (Figure 2) but progress was made in the calibration of the Michigan Basin for geochemical signals via microbial data. In this reporting period, the geochemical survey has been extended to a prospect in the Williston Basin.

## **MICHIGAN BASIN LINEATIONS/FAULTS**

We have mapped a set of significant new major faults in the basin. They extend 100 -150 miles in a Northwest – Southeast direction and have a maximum vertical relief of 500 – 600 feet. The general picture is a structural providence of several broad elongate plateaus bounded by steep fault-controlled escarpments that drop abruptly over 500 feet to form deep-basin valley floors. The valley floors are particularly pronounced in two areas where they form two deep basins separated by a single narrow plateau. The steep ridges are consistent with normal faults and known reservoirs lie close to the faults on the upthrown sides. It has long been known that oil fields in the Michigan Basin define persistent linear trends in the Central Basin and undoubtedly many wells were spotted based on extrapolation of these trends.

The new structural picture of the Michigan Basin will be used to prepare a new exploration model for the basin based on a strategy of conducting surface geochemistry surveys over areas that appear to be gaps



in the current exploration coverage. The new model provides detailed exploration-scale prospect maps in which existing fields can be used as analogs for unexplored areas.

## **GEOCHEMISTRY**

The results of geochemical work to date have been to give a better picture of threshold values that can be used to infer the presence or absence of hydrocarbons. Trost (1993, A Limited Data set Comparison of Headspace Soil Gas and the "MOST" Biogeochemical Technique to Evaluate Drill Site Potential, Bulletin of Association Petroleum Geochemical Explorationists, 9(1), Price (ED), p. 63-80) suggests that the values provided by GMS from their microbial data can be generally classified as:

<b>MICROBIAL VALUE</b>	<b>RANKING</b>	<b>N SAMPLES</b>	<b>PERCENT</b>
0-30	POOR	402	36
30-60	MARGINAL	455	42
60-90	GOOD	199	18
>90	EXCELLENT	46	4

The data we have acquired using microbial technology (MOST) are shown in the two right hand columns above. The sample locations are plotted in Figure 3. Of the nearly 1100 geochemical samples collected, about 22% (245) rank as "Good" or better. (Values for all 1100 samples ranged from 1 to 157.) Using these criteria, our first demonstration well, the Smock 1-23, had microbial values that lay in the ranges "Marginal" to "Good", while the second demonstration well has microbial values that are mainly marginal. The rationale for drilling these projects was to "ground truth" the geochemical data, regardless of whether the geochemistry was good or poor. However, we have turned up a prospect (Mabel Lake) based solely on geochemical data that ranks "Good" to "Excellent". The difficulty here is that the geology does not appear to be as good. We are in the process of evaluating this prospect further.

One of the more obvious potential applications of the new structural data is to develop an exploration strategy for the Central Michigan Basin based on a better knowledge of fault locations and patterns, which in turn is what controls the locations of fields and large-scale fluid movements. We can now see that many fields lie close to the major faults, primarily on the upthrown side. There are a number of areas along the faults where the well control is poor and the contours don't have the same character, that is they are too regular compared to nearby areas that have been more control. These would be likely areas to run geochem profiles.

We have begun to process some new samples from the Myrtle Beach Prospect (Burke County N. Dakota; Figure 8) in the Williston Basin using the GC unit recently set up at Michigan Tech for this purpose. It appears that some of the samples taken contain lignite and we have measured the gas content is several of the samples. It appears that the lignite contains a hydrocarbon signature, which is to be expected since coal is known to adsorb organic gases. In fact, some of the early geochemical gas sampling was done using activated charcoal. Since the Myrtle Beach prospect is adjacent to a abandoned lignite strip mine, it offers an opportunity to investigate a natural geochem sample. Future sampling trips will attempt to specifically recover lignite.

These new data/findings support the project since they could lead to new ways to look for hydrocarbons in intercratonic basins. In that light, we are considering expanding the demonstration to the Williston Basin, which is also an intercratonic basin and where our industry partner has operations in shallow-shelf carbonates.

## **KEY LESSONS**

If we had known going into this project that re-working the existing formation tops data would yield such a detailed picture of the Central Basin structure, we might have focussed on that earlier in the project. However, what made the difference was finally looking at the data on the right scale (i.e. looking at detailed structure contour maps over several counties instead of single fields). It also helped to get the contour intervals set just right, too few and the structure does not show up, too many and the structure is obliterated. In this case it was basically persistence in re-working the data trying different approaches that finally paid off. It also helped immensely that software development had progressed to the point that we were able to redo maps many times, changing and adjusting parameters, which resulted in the discovery.

We are also learning what works and what doesn't in terms of geochemical sampling. We have so far looked at surface iodine, microbial, surface gases, SPME (Site Specific Microextraction) and are now looking at activated carbon. We intend to make some more measurements in the laboratory under controlled conditions, then move the technique to the field this summer. The basic plan will be to bury activated carbon granules for a period of several days to several weeks, then measure the adsorbed gases using the GC.

Several lessons were learned, possibly foremost being that the old drilling records are still a valuable source of data. It does pay to keep looking at the data as new conceptual models and new technologies become available. We feel that we are essentially now just at the beginning of revising the structure and exploration model for the Michigan Basin, and by analogy, perhaps for analogous basins as well. Combined with the progress we have made learning about and using surface geochemistry, we are optimistic that we will emerge with a new paradigm for interior basin exploration.

## **FUTURE WORK**

A number of tasks remain to be done. The most immediate include constructing accurate structural cross-sections that include key horizons, relating the structural data to the gravity data and constructing a model that relates the sedimentary structures to the paleo-rift environment. An example is shown in Figure 4.

We intend to keep pursuing this new direction, refining and filling in the basin model as well as using it to suggest areas that should be targets for surface geochemical surveys and eventually drilling prospects. In that vein, we have several opportunities to run geochemical surveys in the basin with companies that were not part of the original proposal, but who are now sufficiently interested as a result of some of the Eastern AAPG presentations our group made in Kalamazoo last September. Some of these sites that have been sampled are shown in Figure 3.

We also need to keep looking for and evaluating new sites for demonstration wells. We have a second demonstration well, the Bowers in Vernon Field extension, sited and permitted and plan to drill spring or summer of 2002. We have leads on 3 more possible sites, one in Coldwater Field in Isabella County, one in Osceola County (the Orient prospect) and a third also in Isabella County, the Mabel Lake prospect. The

Noble Lake prospect is a result of geochemical profiling; the largest anomalies were found here, as well as the largest number of consistently high anomalies. These results will be reported on more fully in future reports as the prospect matures. We are also working good anomalies near Bear Lake in Manistee County that would likely be a pinnacle reef play.

Work is in progress on sampling the new prospects for geochemical analysis. In addition to the microbial data, which has been the mainstay of the effort so far, we are looking at alternative methods. One is an integrative sampling technique which uses a buried adsorbant that is placed in the ground for several days to several weeks and collects an integrated gas sample that is then extracted and analyzed. This is the preferred technique used by several large commercial companies (e.g. GORE Technologies) and has several advantages, chief among them being that it collects in situ gases under controlled conditions. The drawbacks are that the collector, usually activated carbon or a synthetic adsorbent, will scavenge any gases present, including water. If these gases fill the sites on the adsorbent, the signal of interest will be reduced. It will be necessary to overcome these problems before field trial. It is also a mild drawback that two sampling trips have to be made, but that can be justified if the signal is improved and reliable.

### **Example: Vernon Field Fault**

One of the basin-scale faults we identified happens to run close to the Vernon-Rosebush Fields (Figure 5b). We have tentatively termed this the “Vernon Fault” since Vernon Field lies just above it on the upthrown side. Figures 5a and 5b show the different interpretations of the formation tops data for the Dundee Formation assuming no fault (5a) and a fault present (5b). There are several noteworthy features. One is that the structural contours over both Vernon and Rosebush fields hardly change at all from 5a to 5b; apparently the structures are so tightly constrained that the presence of a large fault less than a mile away has little effect. However the structural picture close to the fault is changed significantly.

A second observation concerns the presence of a large anticlinal structure just south of Vernon-Rosebush that is apparently cut by the main fault. This situation seems unlikely and means that the main Vernon Fault cannot be the only structural element present. Other possibilities include the presence of secondary faults that border the southern anticline or perhaps structures related to salt tectonics, since the Salina Formation is known to be present in the area. The structural picture north of the anticline seems reasonable but the relationship between the fault and the southern anticline needs further work.

### **Example: Myrtle Field Geochem**

As an prelude to the new geochem approach we have sampled the Myrtle Field prospect taking samples for microbial, surface iodine and adsorbed soil gases. The sampling grid is shown in Figure 9. Later this summer we plan to go back and bury activated carbon collectors and compare the results with the commercial data.

## **REPORT BY TASK**

### **Task 1 Project Management – J. Wood**

Task Description - Coordinate all aspects of the project between Michigan Technological University (MTU) at Houghton, Michigan, Western Michigan University in Kalamazoo, MI and Cronus Exploration Company LLC 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.

#### **Subtask 1.1 Technical Aspects - J. Wood**

##### **Policy – Preparation and Enforcement**

The principal subtasks performed were the preparation of this document, including the master outline and coordinating a geochemical sampling party. Separate subcontracts were negotiated and submitted to Western Michigan University and Cronus Exploration Company LLC by Michigan Technological University.

##### **Travel, Students and Expenditures**

To date eight sampling trips have been made to downstate Michigan to Vernon Field and vicinity. Several trips have also been made to potential project sites. Expenses were paid for Wood and Bornhorst to present papers on the project at the Eastern AAPG meeting this past September.

The project presently supports 1 Masters student, Mr. Chris Seaman. Deyi Xie graduated with a Ph.D. this past summer. He was partially supported on this project.

#### **Subtask 1.2 Financial Reports and Accounting - A. Hein**

##### **Financial documents**

All monthly, quarterly and annual statements and documents have been submitted, including the project Management Plan

C. Asiala has organized a system for keeping copies of all expenditures, bills, invoices and related financial documents that concern this project. The university is keeping track of personnel time and pay for all parties. So far only Michigan Tech is drawing personnel salaries from this project.

#### **Subtask 1.3 Archives - C. Asiala**

##### **Archival of Materials and reports**

Electronic copies of geochemical data have been received from vendors and archived in project databases. These databases have been backed up. Printed versions will be included in reports, including this one.

The Atlas program has been altered to plot the GeoChem Sample locations in bubble plots according to the type of chemical concentration chosen by the user. The GeoChem data can be plotted simultaneously with the well locations or it can be plotted separately. The GeoChem data can also be edited from within the Atlas program. The GeoChem data is stored in 2 tables separate from the well data tables. The first

table holds the Permit (unique number assigned to the sample) and its latitude/longitude coordinates. The second table holds the Permit, type of concentration, and concentration value. This allows multiple GeoChem concentration values for each sample.

The Subsurface Visualization Lab Web Site (<http://www.geo.mtu.edu/svl>) has been updated with reports and figures that pertain to the project. Ongoing updates will be added throughout the project.

#### **Processing of DEM and SDTS files**

In addition to the work in the first Budget Period on Digital Elevation models (DEMs), work has expanded this Budget Period to include gravity data from NOAA on the Central Michigan Basin. This data will be integrated with the rest of the project data and used to help interpret the structural model for the Michigan Basin.

### **Task 2 Reservoir Characterization – W. Harrison**

Task Description - 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.

#### **Subtask 2.1 Surface Geochemistry – T. Bornhorst**

Work on this task will continue in Budget Period II. To date over 1500 samples have been collected from 1090 locations.

#### **Subtask 2.2 Reservoir Geology – S. Chittick**

##### **Subsurface data**

We have continued to update and edit subsurface data in our master database files. Presently most of our efforts are going into correcting bad entries and removing duplicate records.

#### **Subtask 2.3 Engineering Parameters- W. Harrison**

No activity this period. Work will take up when drilling targets have been selected for the Phase II demonstration wells.

#### **Subtask 2.4 2D Seismic- W. Quinlan**

Acquisition of new seismic data has been deleted from the project task list; instead we will acquire and process existing data.

### **Task 3 Analysis of Producibility Problem(s) – W. Quinlan**

#### **Subtask 3.1 Drilling – E. Taylor**

No activity this period.

#### **Subtask 3.2 Well Logging – S. Chittick**

No activity this period.

## **Task 4 Technology Transfer – W. Harrison**

Task Description - Transfer of the technology is recognized as a crucial element in this project. Special efforts will be made to deliver the results in a usable 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

As a result of presentations made on the project results at the Eastern AAPG meeting in Kalamazoo last September, several individuals have expressed interest in ATLAS and we are in the process of transferring the program to them.

### **Subtask 4.1 PTTC Workshops – W. Harrison**

#### **Workshops**

A mini-workshop was held in Kalamazoo at the EAAPG meeting in September, 2001. J. Wood presented recent developments in the ATLAS program. There were about 30 attendees.

#### **Case histories**

None

#### **Tutorials.**

None

### **Subtask 4.2 Reports – J. Wood**

#### **Publications**

Publish project results in DOE reports and in scholarly journals.

#### **Presentations**

Wood, J. R., 2001 – September EAAPG in Kalamazoo, MI. Presentation of project to date, including last demonstration well and surface geochemistry results.

Wood, J. R., 2001 – September EAAPG in Kalamazoo, MI. Presentation ATLAS software.

Bornhorst, T. J., 2001 – September EAAPG in Kalamazoo, MI. Presentation of project to date, including surface geochemistry results.

Barnes, D., 2001 – September EAAPG in Kalamazoo, MI. Presentation of structural data and interpretation for Vernon Field.

Wood, J. R., 2000 – June SPE Meeting in Long Beach, CA. Presentation of project to date, including surface geochemistry results

Harrison, W. B., 2000 – June DOE Contractors Meeting in Long Beach, CA. Presentation of project to date, including surface geochemistry results

Present results at local and national meeting of geological societies, such as the AAPG.

### **Subtask 4.3**

#### **WEB Site**

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

## FIGURES



PERIOD	EPOCH	SEQUENCE	Rock Groups	Formations	Lithology
QUATERNARY				Red Beds	
JURASSIC				Grand River Fm.	
	LATE	ABSAROKA		Saginaw Fm.	
PENN.	EARLY		GRAND RAPIDS	Bayport Ls.	
				Michigan	
MISS.	LATE			Marshall Fm.	
	EARLY			Coldwater Sh.	
				Ellsworth Sh (W.)	
				Antrim Sh. (E. )	
MISS./DEV UNDIVIDED					
	LATE		TRAVERSE	Squaw Bay Ls	
				Alpena Ls	
				Bell Sh	
DEVONIAN	MIDDLE	KASKASKIA		Rogers City Ls	
				Dundee Ls	
			DETROIT RIVER	Lucas Fm.	
				Amherstburg Fm.	
				Bois Blanc Fm.	
				Garden Island Fm.	
	EARLY		BASS ISLANDS		
	LATE		SALINA	G Unit	
				F Evaporites	
				E Unit	
				D Evaporite	
				C Unit	
				B Evaporite	
				A-2 Carbonate	
				A-2 Evaporite	
				A-1 Carbonate	
				A-1 Evaporite	
SILURIAN	MIDDLE	TIPPECANOE	NIAGARA	Brown Niagaran	
				Gray Niagaran	
				White Niagaran	
				Clinton Sh.	
			CATARACT	Cabot Head Sh	
				Manitoulin Dol.	
			RICHMOND	Queenston Sh	
	EARLY				
			EDEN	Utica Sh	
	LATE			Collinwood Sh.	
			TRENTON - BLACK RIVER	Trenton Group	
				Glenwood	
	MIDDLE			St. Peter Ss	
				Shakopee Dol.	
			PRARIE du CHIEN	New Richmond Ss.	
				Oneota Dol.	
	EARLY			Trempealeau Fm.	
				Franconia Ss.	
				Dresbach Ss.	
	LATE		LAKE SUPERIOR	Eau Claire Fm.	
				Mt. Simon Ss.	
				Jacobsville Ss.	
	EARLY & MID.				
CAMBRIAN		SAUK			

Figure 1. Generalized stratigraphic column for Michigan Basin.

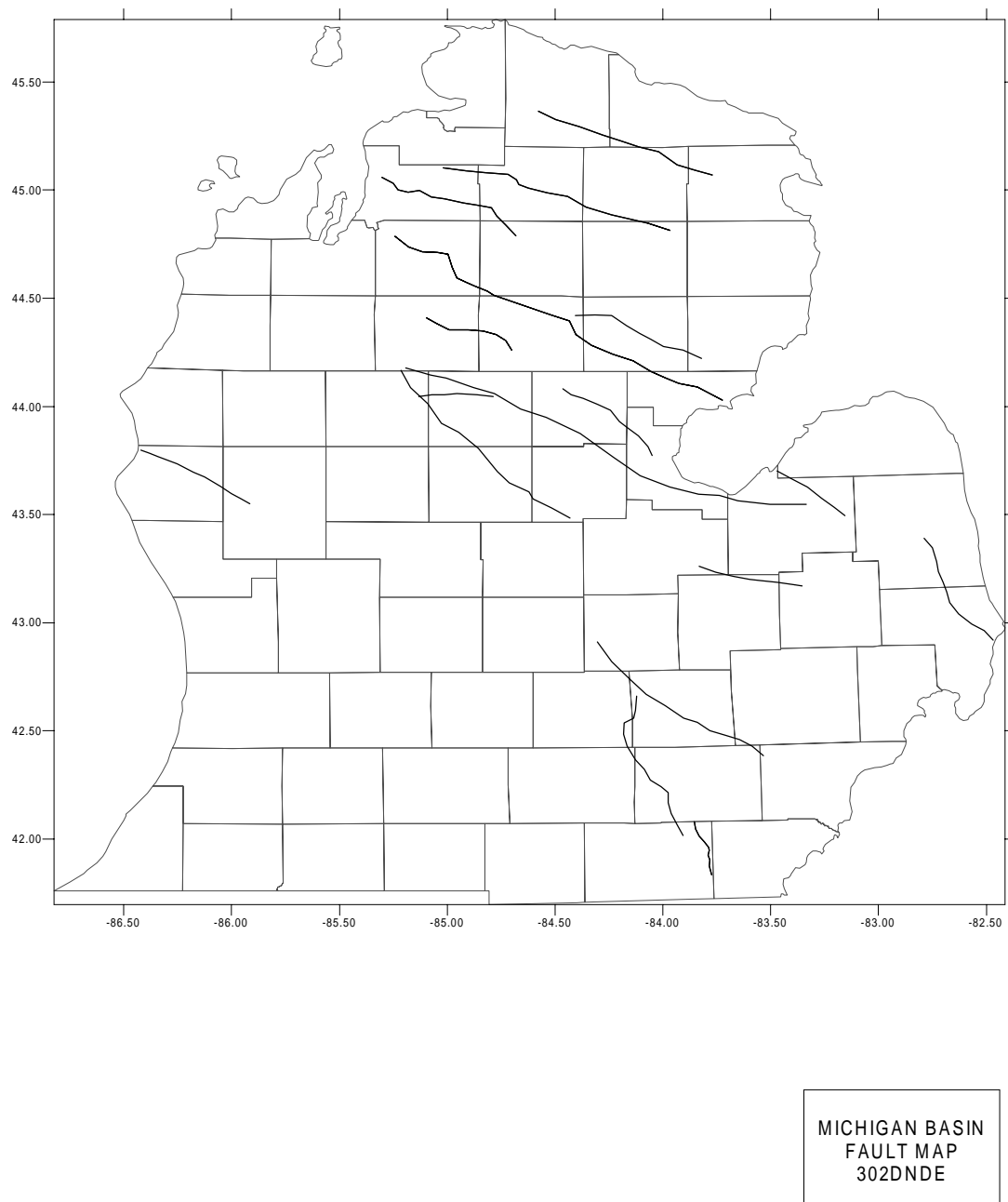


Figure 2. Index map showing major faults in the Central Michigan Basin.

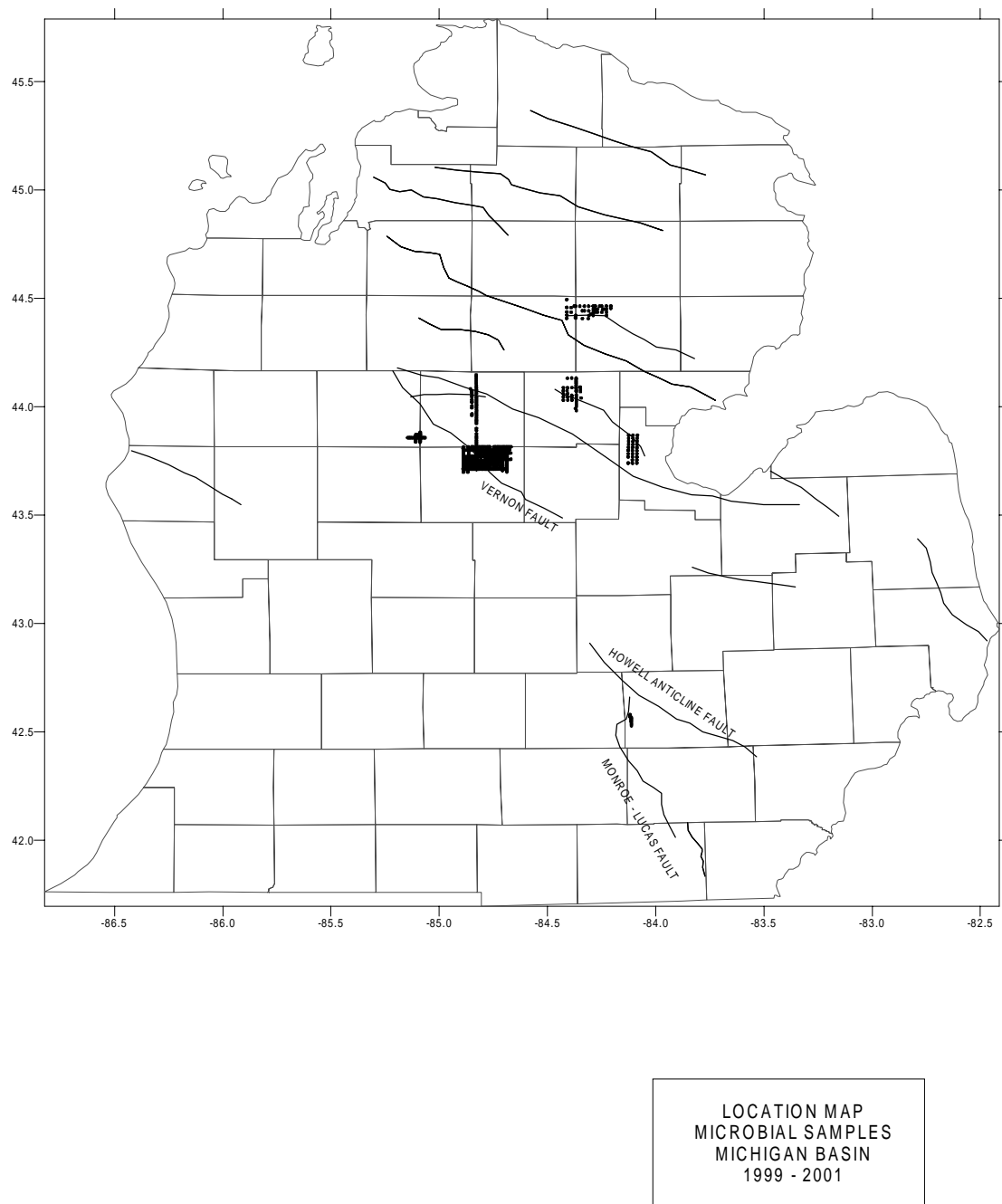
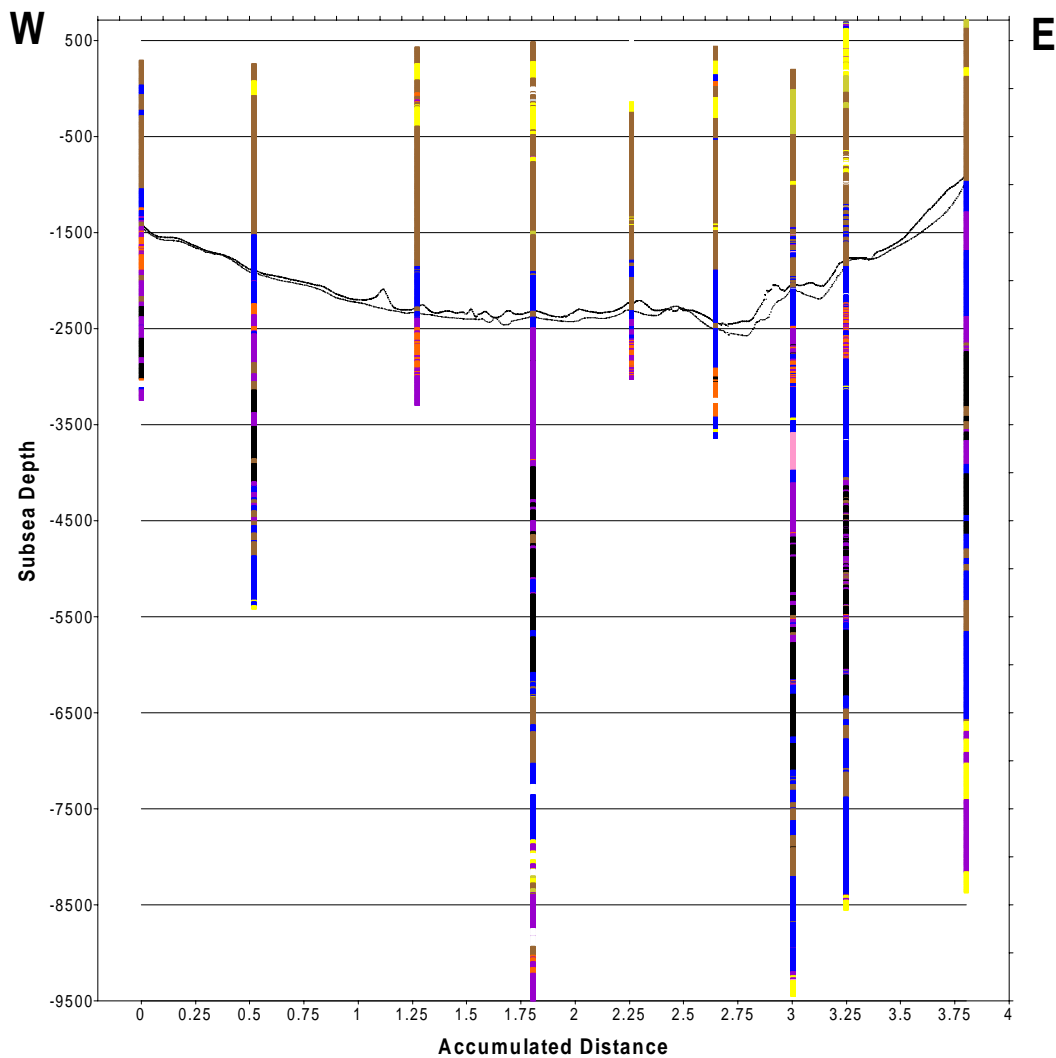


Figure 3. Location Map of Microbial Samples.

# East-West Lithologic Cross Section



## Lithology Legend

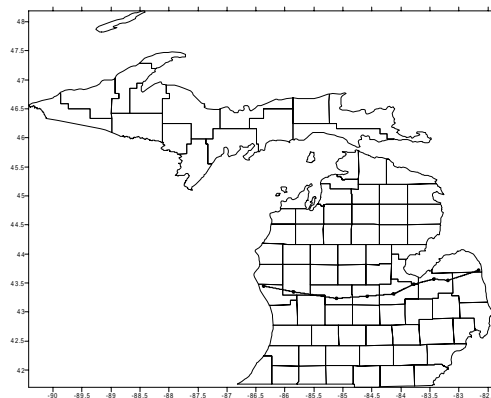
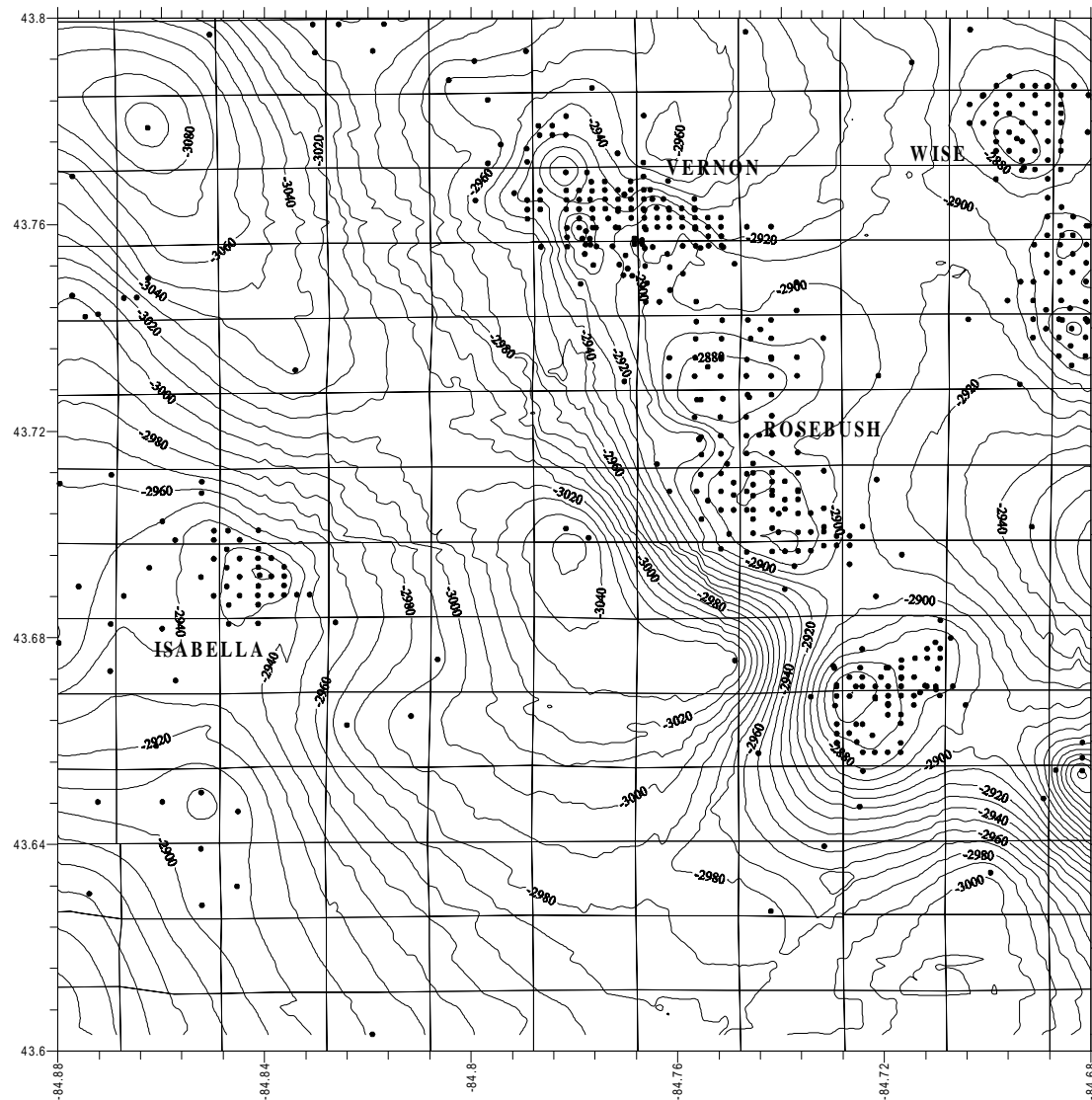
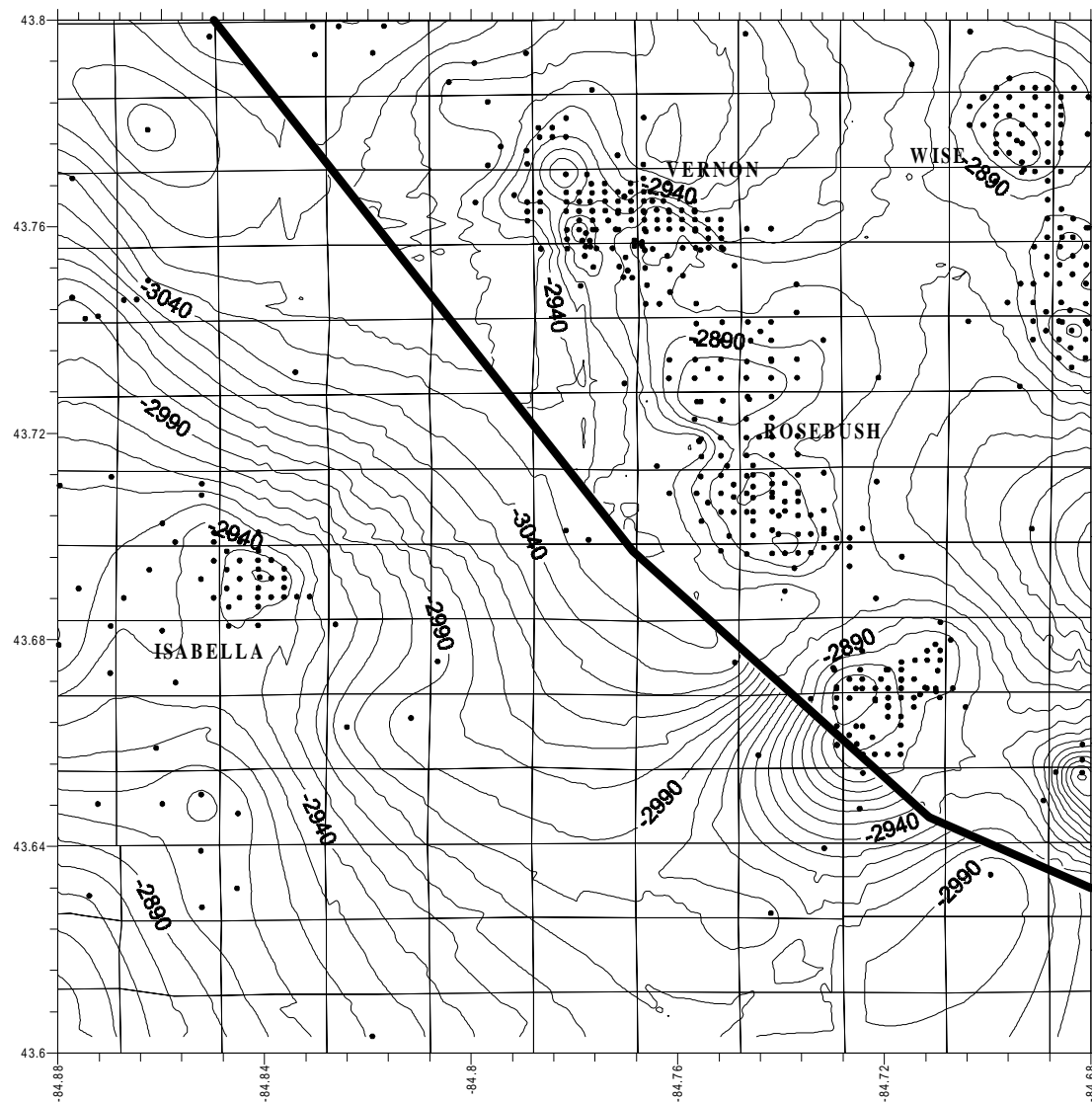


Figure 4. East-West Lithology Cross-Section, showing the Bell Shale (top curve) and the Dundee (bottom curve) Formations.



VERNON FIELD  
ISABELLA COUNTY, MICHIGAN  
CONTOURS ON TOP DUNDEE  
CI = 10 FT.

Figure 5a. Contour Map on top of Dundee Formation for Vernon-Rosebush Fields. No fault.



VERNON FIELD  
ISABELLA COUNTY, MICHIGAN  
CONTOURS ON TOP DUNDEE  
CI = 10 FT.

Figure 5b. Contour Map on top of Dundee Formation for Vernon-Rosebush Fields with fault.

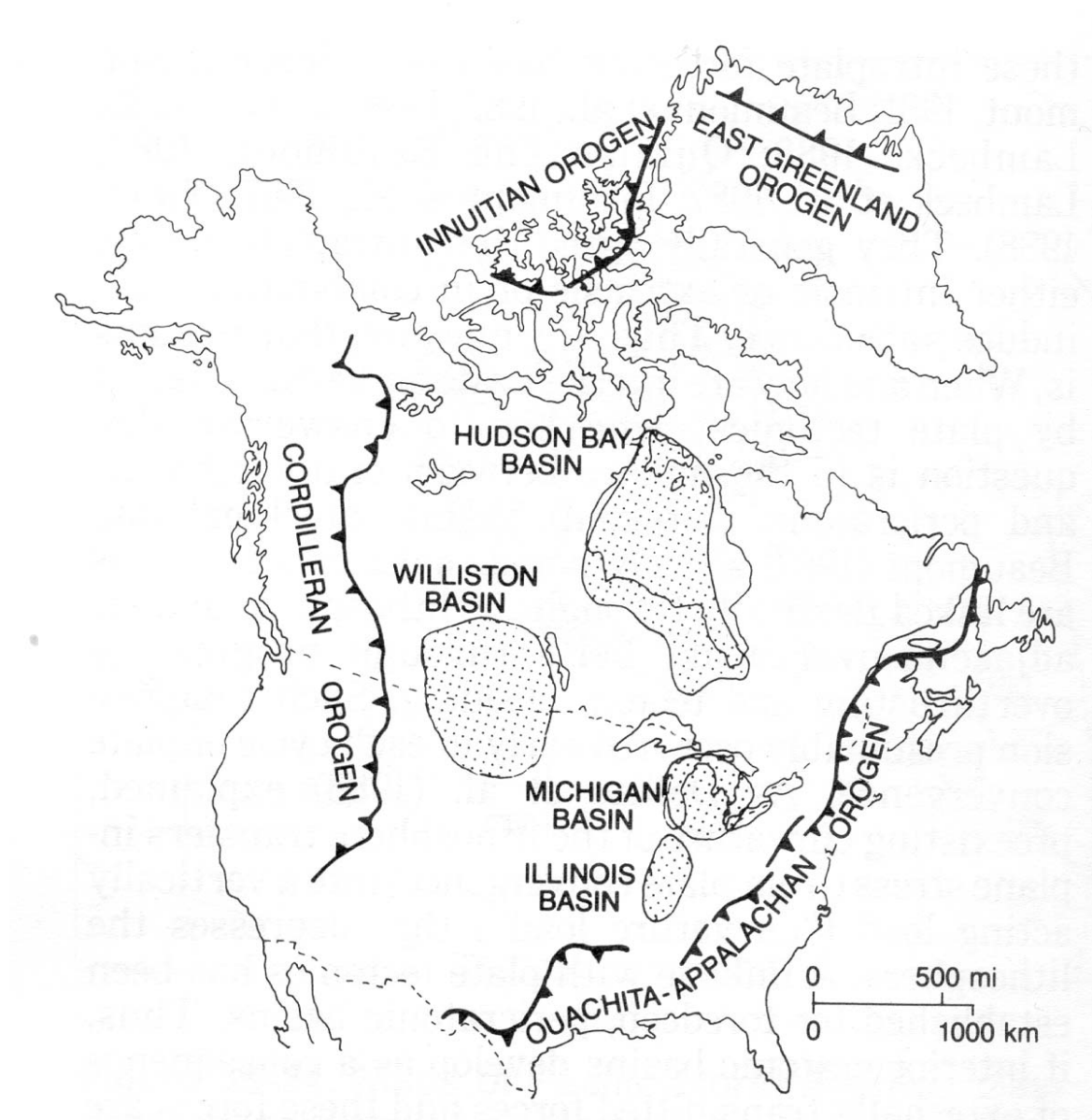


Figure 6. Index map showing locations of Michigan and Williston Basins.

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

Figure 7. Generalized stratigraphic column for



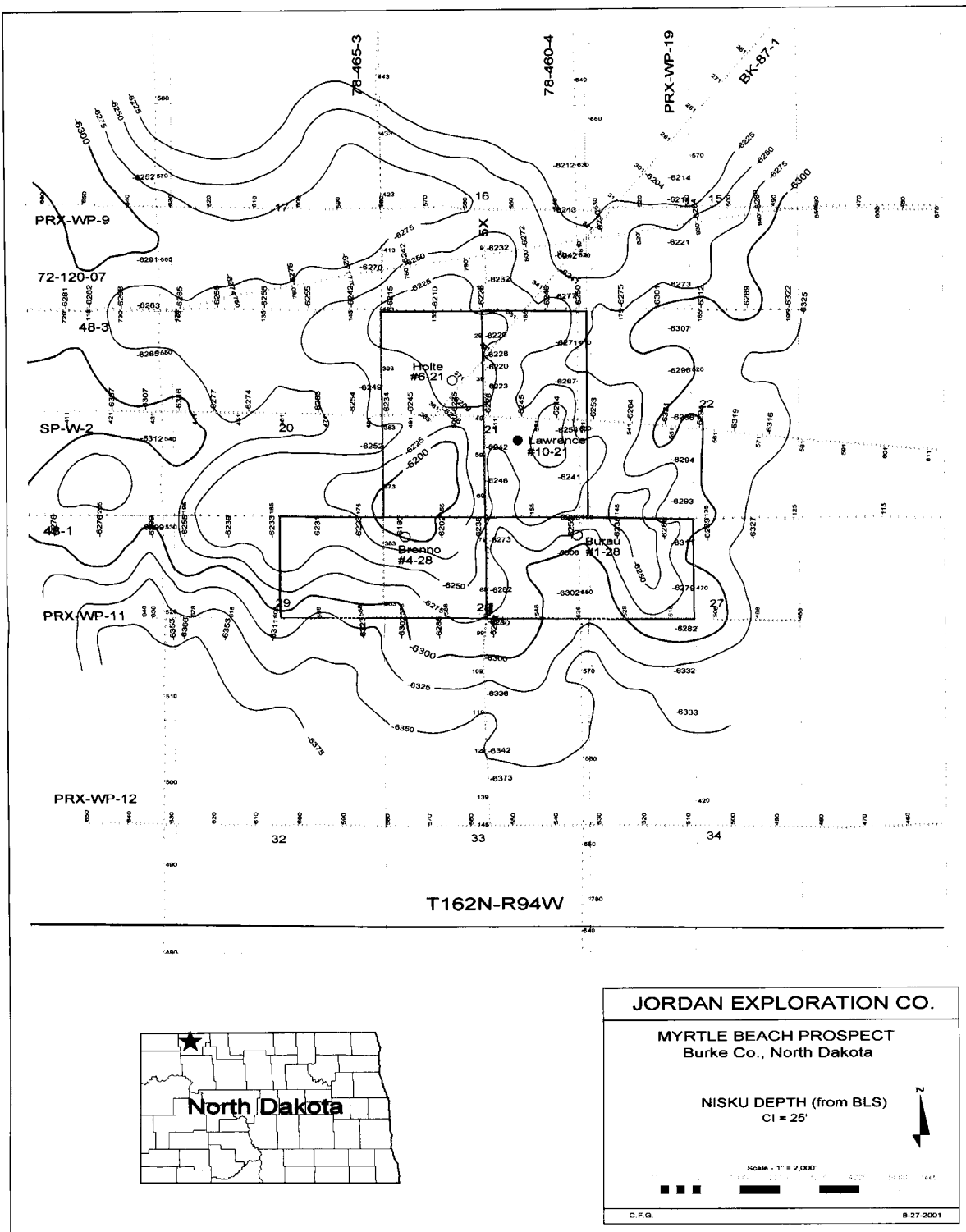
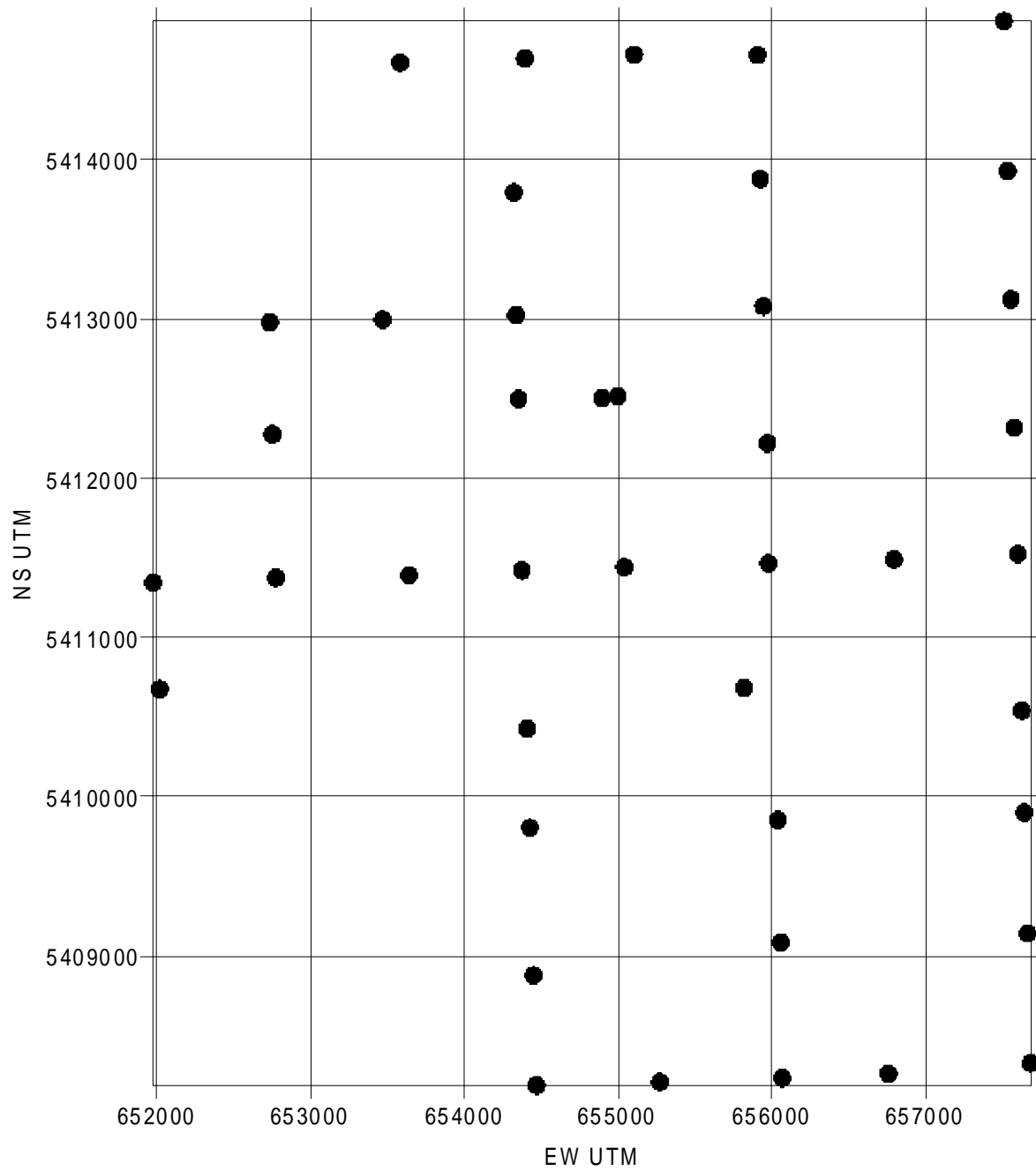


Figure 8. Location map for Myrtle Beach Prospect, N. Dakota.



SAMPLE GRID  
MYRTLE BEACH PROSPECT  
BURKE COUNTY, N. DAKOTA  
UTM ZONE 13

Figure 9. Location Map of Microbial Samples at Myrtle Beach Prospect, Burke County, N. Dakota.