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ADVANCED CHARACTERIZATION OF FRACTURED RESERVOIRS IN CARBONATE ROCKS: THE MICHIGAN BASIN

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ABSTRACT

Progress in year 2 of this project is highlighted by the completing the writing and testing of the project database, *Atlas*, and populating it with all the project data gathered to date. This includes digitization of 17,000+ original Scout Tickets for the Michigan Basin. Work continues on the Driller's Reports, where we have scanned about 50,000 pages out of an estimated 300,000+ pages. All of the scanned images have been attached to *Atlas*, the visual database viewer developed for this project.

A complete set of the 1/24,000 USGS DEM (Digital Elevation Models) for the State of Michigan has been downloaded from the USGS Web sites, decompressed and converted to ArcView Grid files. A large-scale map (48 inches x 84 inches) has been constructed by mosaicing of the high-resolution files. This map show excellent ground surface detail and has drawn much comment and requests for copies at the venues where it has been displayed. Although it was generated for mapping of surface lineations the map has other uses, particularly analysis of the glacial drift in Michigan. It presents unusual problems due to its size and we are working with vendors on compression and display algorithms (e.g. MrSID ©) in an attempt to make it available over the Internet, both for viewing and download.

A set of aeromagnetic data for the Michigan Basin has been acquired and is being incorporated into the study. As reported previously, the general fracture picture in the Michigan Basin is a dominant NW-SE trend with a conjugate NE - SW trend. Subsurface, DEM and gravity data support the interpretation of a graben-type deep basement structural trend coincident with the Michigan Basin Gravity High. We plan to incorporate the aeromagnetic data into this interpretation as well.

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Figure 2. Simplified stratigraphic column for central Michigan Basin

Figure 3. Structure contour map on Top of Dundee Formation

EXECUTIVE SUMMARY

The main objective of this project is for a university–industry consortium to develop a comprehensive model for fractured carbonate reservoirs based on the “data cube” concept using the Michigan Basin as a prototype. Results to date include digitizing of well records, detailed mapping of several key fracture-dominated fields (Deep River and N. Adams), writing code for a new software programs (“*Atlas*”), and acquisition of seismic data. The negotiations to acquire a 3D seismic survey shot by Marathon Oil Company over Stony Point Field have unfortunately fallen through and it now appears unlikely we will have access to this data.

The general fracture picture that is emerging in the Michigan Basin is a dominant NW – SE trend that manifests itself on a field scale and can be mapped in outcrop. The conjugate direction, roughly, a NE – SW trend is also established in some fields. Data (mainly gravity) suggests that this trend is related to a deep basement structural trend coincident with the Michigan Basin Gravity High. This data has been interpreted as evidence for an old rifting episode early in the Proterozoic history of the Basin. The locations and geometry of many gas and oil fields in the central part of the Michigan Basin are consistent with this interpretation: elongated fields oriented NW – SE or SE – NW with many on the margins of the gravity high.

We have now been able to document this feature on a field scale by mapping the “Top of Porosity” for about a dozen in the Dundee and Trenton Formations. As discussed in earlier reports, a common practice in Michigan when developing prospects is to map a parameter termed “Top of Porosity”, which is essentially the first encounter of the drill bit with diagenetic dolomite. This parameter is recorded in records (scout tickets and driller’s reports that have been digitized as part of this project) for several of the carbonate units in the Michigan Basin, including the Dundee and Trenton Formations. In many reservoirs, the main pay zone is altered limestone that occurs off structure. Most of these traps are classified as stratigraphic. The main difficulty with mapping this feature is that it is not a formal stratigraphic unit and was only recorded “unofficially” in driller’s reports. Until this study, there was no systematic attempt (except for internal confidential company reports) to record this parameter. It is necessary to read each mention off driller’s reports and manually read them into a database. *Atlas* 3.0 has been helpful in this regard and we have compiled a large body of data. However, this task is dependent on scanning the driller’s reports and so lags behind that task.

We have continued to make good progress in scanning the driller’s reports and incorporating them into the *Atlas* database as they are acquired. However, much effort is still required.

INTRODUCTION

Carbonate rocks have been selected for this study because in many basins worldwide, fractured carbonate zones form important oil and gas reservoirs. Termed “dolomite chimneys”, in the Michigan Basin, they have long been among the most prolific producers of hydrocarbons in the world. However, key aspects of their origin(s), distribution and architecture have been enigmatic. They have been difficult to find and once found, many have proven difficult to produce efficiently. The Michigan Basin is well suited to serve as a model for fractured reservoirs. It is a mature basin that contains almost 50,000 gas and oil wells with extensive data and rock samples. Over 150 million barrels oil has been produced from fractured carbonate reservoirs in Michigan and adjacent states. The Dundee Formation alone has produced over 350 million barrels, approximately 40-50 million from fractured, dolomitized reservoirs. It has been estimated that nearly this amount of hydrocarbons remains to be recovered.

The data from driller’s reports continues to be collected and scanned and results to date are now on the Internet. Several counties are now complete and work is in progress on several others (Figure 1). We are working to make the software packages required to display and manipulate the data available as well. The software will permit visualization and interpretation on both large and small scales. The main deliverable will be a data cube for the Michigan Basin that will include:

- A library of formation tops picks (300,000+)
digitized well locations (latitude & longitude; 50,000+)
scanned images of well header records
digitized and interpreted logs of key wells
hydrocarbon logs,
- engineering data, and
- key horizons picked from 2D & 3D seismic data, if possible.

The primary vehicle for the basin model has been switched from ER Mapper to ArcView. The main reasons being that ArcView is better suited for software development (e.g. *Atlas* is written around the *Map Objects Lite* ©control) and is emerging as a standard for archiving and transmitting spatial data.

RESULTS AND DISCUSSION

Task 1. Project Management

Subtask 1.1 Technical Aspects

Project management continues to operate smoothly: links have been established between the main Michigan Tech operations site and the satellite sites in Kalamazoo, Traverse City and Tampa FL. Two face-to-face meetings with all personnel were held, one

meeting in Traverse City, and one in Tampa. All senior team members (Wood, Harrison, Luo, Chittick) will attend the spring AAPG meeting in New Orleans.

As reported last time, Michigan Tech is part of the National InterNet2 program that is essentially a project to upgrade the current Internet by making it faster and with wider bandwidth. Our DOE project was suggested as one that might make use of the added capabilities, particularly the live conferencing. The InterNet2 connections may not be set up and operating in time to make much difference in this project, since we have only 12 months remaining on it. However, we will stay involved in the project since it will likely be the main vehicle for electronic communication in the future.

Subtask 1.2 Financial Reports and Accounting

Project expenditures are proceeding according to plan. All necessary reports have been filed with DOE Pittsburgh.

Task 2. Basin Analysis

Subtask 2.1 Geology

Lineation Analysis

Last time we reported that Digital Elevation Models (DEMs) compiled by the USGS (U. S. Geological Survey) were well suited for analysis of surface lineations in the Michigan Basin. (A DEM is a grid of surface elevations at various resolutions generally taken from the Mylars of old USGS 7.5 Minute quadrangle maps, resampled and compiled.) We have pursued that direction for most of this last reporting period and have made considerable progress. Data for the entire State of Michigan has now been secured and processed. We have produced large-scale DEM maps of the Lower Peninsula using ArcView and have begun to make the results public. The results have been spectacular; lineations are apparent everywhere and we are now beginning to map them systematically and looking for correlations with known subsurface fractures. We believe that this is the first time anyone has used these data to mosaic an entire state together. We are discovering a number of new features, including possibly an impact structure. The brief public showings that we have made so far have met with enthusiastic response and we think this aspect of the project will be a great success story. It is low-cost and can be used anywhere DEM data is available, including the entire U. S.

Some of the problems with the DEM data mentioned in the last report have been addressed. Specifically:

- The USGS high resolution DEM data set is now complete for the Michigan Basin.
- 2 The conversion from meters to feet was finished.
- 3 Processing errors that “stripe” some of the digital image in an east west direction still remain (Figure 1).

This last problem is difficult to resolve. The USGS will redo the quad for \$300/map or a commercial firm will do it for about \$80. Since we have about 100 of the 7 ½ minute quadrangles in this state, either of these solutions is expensive.

Also, we contracted with Geologic Data Systems (Denver CO.) to perform a lineament study over Arenac County, Michigan using 1:100,000 LandSat 5 satellite imagery and 1:80,000 aerial photography. Geologic Data Systems was able to pick many lineaments, essentially using aerial photographs. We will compare Geologic Data Systems methodology for determining lineaments with picking lineaments from DEMs and either combine the two methods or adopt one or the other on the outcome of the comparisons.

Basin wide mapping has begun. All Michigan well locations up to 1997 have been input into ArcView. Formation top data will be examined and corrected as necessary, gridded, loaded into ArcView and displayed as basin and field scale maps. We intend to do this for all the key horizons in the Michigan Basin, as indicated by the formations listed in the stratigraphic column for the central Michigan Basin (Figure 2). An example of this work is the gridded and contoured structure map for the top of the Dundee Formation (figure 3). Other data, such as initial production and cumulative production is more appropriately viewed as bubble plots on basin and field scales, to highlight linear trends.

Subtask 2.2 Geophysics

2.2.1 Seismic

Three 2D seismic lines were obtained from Marathon Oil Company near the Crystal Field in Montcalm county (MOC), loaded into GeoQuest and processed in an attempt to elucidate Dundee structure. The seismic data was shot targeting deeper plays and thus has low fold and offset to adequately resolve shallower plays such as the Dundee. From structure maps, isopach maps and initial production bubble plots, it is apparent that the Dundee of the Crystal field was faulted and probably karstified. The low fold and offset coupled with unknown static conditions creates a condition of low signal to noise ratio, making it difficult to resolve the shallow structure and fractured nature of the Dundee in the Crystal field (T. Bulloch, 1999). Bay Geophysical of Traverse City, Michigan has however, indicated that they have exclusive processing techniques, which may be able to resolve shallow low fold structure. This project will attempt to acquire data processed by Bay Geophysical, which resolves shallow structure with 2D data.

2.2.2 Borehole

The use of borehole data in this project is continuing, mostly at Western Michigan University.

Subtask 2.3 Hydrology

This task has started with the analysis of the main hydrologic units in the Michigan Basin, the basement configuration, the Traverse and Dundee Formations (Figure 3). This task requires that the data cube be available and that has only occurred recently.

2.3.1 Fluid Pathways

This task is proceeding in tandem with the basin model. It has much the same problems as the mapping of the Top of Porosity in that it is necessary to read each driller's report for mention of hydrocarbon shows.

2.3.2 Flow Model

2.3.3 Gas and Oil Trapping

The show data discussed in 2.3.1 above should point toward known gas and oil fields. Thus the trapping mechanisms may be elucidated as well since we would anticipate that the shows would terminate at seals, which are generally shales, tight limestone or salt in the Michigan Basin. We will plot the oil and gas shows along with producing oil plays in a three dimensional display to show migration routes and oil and gas trapping mechanisms.

Task 3. Quantification and Mapping (WBH)

Subtask 3.1 Data Acquisition

Data Cleanup and Digitization

Several aspects of this task are completed. Over 17,000 scout tickets have been digitized as TIF images and added to the Atlas database. These are all of our currently available scout tickets. We have begun work digitizing driller's reports as multiple page TIF images. Digital well logs are being acquired from oil and gas company donations and in house digitizing. Recently, over new 5,400 wells were added to our database, bringing the total number of well locations to approximately 54,000.

3.1.2 Gridding

The 7 ½ minute DEM grid for the entire State of Michigan has been completed. Work is now focussed on upgrading the individual data elements and plotting the large-scale maps.

3.1.3 Database Management

All data associated with this project to date has been placed into a MS Access database as promised. In addition, all documents related to the project (reports, software, etc.) have

also been placed in a digital database that consists of the MS Windows normal file structure. The database can be accessed using *Atlas*.

Subtask 3.2 Mapping and Visualization

3.2.1 2D Mapping

This task is now completed with regard to the surface grid. This includes cultural data, as well as hydrologic. Attention is now focussed on mapping the key subsurface horizons now that the database containing the formation tops is available.

3.2.2 3D Mapping

The 3D code for displaying the gridded data described in 3.1.2 above is finished and ready to be incorporated into the project software library. The code has been written in Visual Basic (VB) and is available for testing.

3.2.3 Reports and Maps

Michigan Atlas – In addition to the DEM data described above, most of the progress for this reporting period has come in the development of the Atlas software. This program is turning out to be a very effective tool for consolidating and displaying the project results. We have begun to release the program to a few selected operators in the Michigan Basin for evaluation and feedback. Atlas can be used effectively to determine if certain data exists for a specific well or a group of wells. Well locations are color-coded indicating which wells have the user-requested data (Figure 5). A detailed summary (30+ pages) of this software will be published in the Annual Report for 1999.

Subtask 3.3 Fracture Analysis (WBH)

Literature data has been compiled on outcrop fractures in the Michigan Basin. Samples for petrographic examination have been collected and are being prepared for petrographic examination. These data will be digitized and plotted. Maps and reports will be available in the 1st annual report.

Task 4 Geochemical Studies

Subtask 4.1 Diagenesis

Work is in progress to retrieve “top of porosity” picks from as many wells as possible. This will be aided by examining the scanned driller’s reports, using the program Atlas 3.0. “Top of porosity” was usually noted in fields with producing wells and generally indicates diagenetic dolomite. The difference between the formation top picked before “top of porosity” and “top of porosity” is unaltered limestone cap rock.

Subtask 4.2 Fluid Geochemistry

A database on subsurface fluid chemistry is being compiled for the Michigan Basin as part of a student project. Results will be presented in the annual report. Fluid analyses will be correlated with latitude & longitude and then plotted according to the formation of origin to see if any significant trends or correlations are present.

Subtask 4.3 Hydrocarbons

Work on hydrocarbons will begin the 2nd year of the project.

Task 5. Technology Transfer (WBH & JRW)

Subtask 5.1 Public Outreach

5.1.1 Internet (WWW)

A new Internet site for this project has been constructed on the Michigan Tech server. Additional information and reports continue to be placed on this site and the site at Western Michigan.

5.1.2 Newsletter

The newsletter has been incorporated into the Web site to make it more readily available and to ease distribution problems and costs.

Subtask 5.2 Workshops (WBH)

A PTTC workshop organized by Harrison was held in Mt. Pleasant in February of this year. Atlas was presented, along with the DEM work.

Subtask 5.3 Meetings

5.3.1 DOE Contractor Meetings

Both Wood and Harrison plan to attend the DOE Contractors meeting scheduled for June, 2000 in Denver.

5.3.2 National and Regional Meetings

A booth was staffed at the Exhibition Hall at the Annual AAPG Meeting this April in New Orleans by project personnel and a poster of the project was displayed.

CONCLUSIONS

For this reporting period, the project is still on schedule and is still meeting all major goals. The Atlas program has emerged as the primary deliverable from the project and has been made available to the public since December of 1999. The data cube for the surface of the Michigan Basin is complete and work is continuing on populating the subsurface database.

Sufficient digital data has been collected to begin analysis of basin scale fractures (Figure 3). In the next period we expect to have structure contour maps completed for all the key horizons in the Michigan Basin. The work done on the Dundee Formation shows “stacked” contours indicative of large-scale faults. We will see if these patterns are present in formations above and/or below the Dundee.

Work is still continuing on mapping the Top of Porosity in the Basin, as well as data for hydrocarbon shows. This is time-consuming since the data have to be read off the driller’s reports or scout tickets. Scanning the images and incorporating them into the Atlas program has greatly facilitated this work.

Work on the hydrology of the Basin will begin this period now that the subsurface data is available for construction of a basin model.

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“Oil and Gas Fields of the Michigan Basin” 1968, Vol. 1, Michigan Basin Geological Society, M. S. Wollensak, Ed., Department of Geological Sciences, Michigan State University, E. Lansing, MI.

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FIGURE CAPTIONS

Figure 1. Map of Michigan Basin with county outlines showing progress on scanning driller's reports. Counties shaded darks are complete while the stippled pattern shows work in progress.

Figure 2. Stratigraphic column for central Michigan Basin showing location of Dundee Formation (Middle Devonian).

Figure 3. Structure contour map on top of Dundee Formation. CI =100 ft. Preliminary map contains unedited data points that plot as "bulls eyes", likely data "busts" that need to be verified and removed if in error. Note that the map also contains clustered or stacked contours at several locations, notably the lower SE portion of the map and the upper (Northern) portion. These stacked contours may indicate faults.

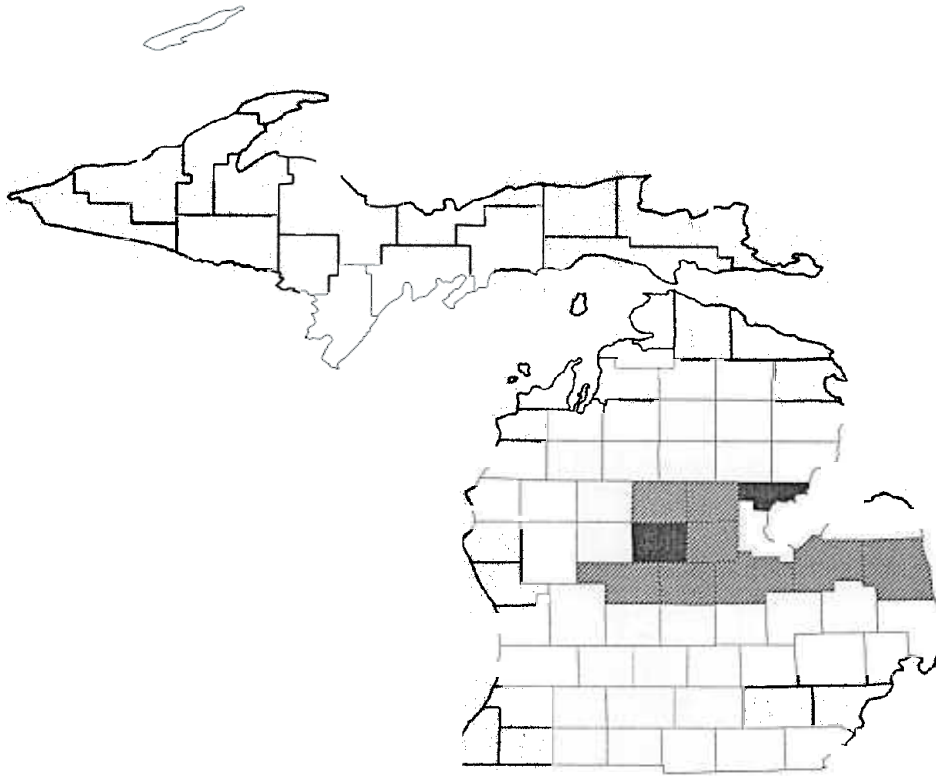


Figure 1. Index map for Michigan counties showing progress in scanning drillers reports from paper copy to electronic files. Filled counties are complete, stippled counties indicate partially complete.

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

Figure 2. Stratigraphic column for central Michigan Basin showing location of Dundee Formation (Middle Devonian)



Figure 3. Structure contour map on top of Dundee Formation. CI =100 ft. Preliminary map contains unedited data points that plot as “bulls eyes”, likely data “busts” that need to be verified and removed if in error. Note that the map also contains clustered or stacked contours at several locations, notably the lower SE portion of the map and the upper (Northern) portion. These stacked contours may indicate faults.