Reservoir Characterization & 3D Models of Mt. Simon Gas Storage Fields in the Illinois Basin

Annual Technical Progress Report

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Abstract

The Cambrian Mt. Simon Sandstone forms the reservoir for many gas storage sites in northern Illinois. Detailed characterization of this reservoir unit will improve understanding of gas injection and production processes, and can be used at a later time to prepare reservoir fluid flow simulations for optimal field management.

Detailed studies using Landmark Graphics software at Manlove and Herscher fields have provided benchmark reservoir characterization frameworks that can be applied elsewhere. The Manlove study, with over 300 wells, 35 of which have core analyses, has progressed relatively quickly, primarily because digital logs were available. Internal correlation markers, cross-sections, structure and isopach maps, and both preliminary Vshale and porosity 3D models have been completed. Final refinements to porosity calculations will be made to improve the model.

The Herscher field study is nearly complete. Logs in Herscher from approximately 250 wells have been digitized and loaded into the Landmark workstation. Formation correlations and field mapping have been completed. A method different from that used at Manlove Field was used at Herscher to calculate porosity because of the lack of modern porosity logs, the strong “gas effect” noted in the existing GR-Neutron logs and the existence of core data from only six wells in the field. Porosity was calculated from the Vshale values and a transform that was developed from the limited core data. Mapping and initial 3D models of porosity for the field have been completed. Both the Elmhurst and Mt. Simon sandstones are porous and friable with little cementation. The finer-grained sandstones in these reservoir units contain abundant k-feldspar and quartz grains, whereas the more common coarse-grained sands are composed primarily of quartz grains with abundant primary porosity.

Final quality checking of regional formation tops data for all wells of northern Illinois is nearing completion. Data from over 9000 wells have been compiled and several preliminary regional maps have been prepared. Although the Mt. Simon is penetrated by only 879 wells, primarily at existing gas storage sites, regional mapping of the Mt. Simon projected from over 8000 shallower additional wells has outlined its structural configuration. A conformable mapping method that combines isopachs and structure maps derived from several shallower horizons will be used to make a projected structure map of the top of the Mt. Simon. This map will help identify possible future storage sites.

A comprehensive paper on this project was submitted to and accepted by the AAPG. It will be presented at their May 2003 annual National Meeting in Salt Lake City. In addition, a PTTC tech transfer workshop on the project has been scheduled for presentation in Pontiac, Illinois on March 19, 2003, at a seminar co-sponsored with the Gas Storage Chapter of the SPE. An abstract on the Herscher Field study was submitted to the Eastern Section AAPG for presentation at their September 2003 meeting in Pittsburgh, PA.

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Executive Summary

Digital data have been compiled and organized to characterize the Mt. Simon Sandstone gas storage reservoirs in two fields in Illinois, the Manlove Field in Champaign County and the Herscher Field in Kankakee County, (Figure 1) in order to improve the understanding of gas injection and production processes. These reservoir characterizations can be used at a later time by the operating company to develop reservoir fluid flow simulations for optimal field management. Preliminary regional structure maps of the top of the Maquoketa Shale, Galena-Platteville Group and Mt. Simon Sandstone have been prepared to identify possible locations for new storage fields.

Manlove Field, a 150 BCF aquifer gas storage field in Champaign County, Illinois, operated by Peoples Energy Corp., is formed by a closed anticline in the

Cambrian Mt. Simon Sandstone, a quartz sandstone aquifer about 4000 feet underground with a sealing caprock formed by the overlying Cambrian Eau Claire Formation. The field, located about 130 miles south of Chicago, began operation in 1966. Maximum daily withdrawal is nearly 1 BCF. Gas is transported to the Chicago market via two large- diameter company-owned pipelines.

Digital well log and core data for the Manlove field were compiled using Landmark Graphics Openworks software. Logs from over 300 wells and core analyses from 35 wells provided the framework for this study. Formation and internal Mt. Simon correlations, cross sections, structure and isopach maps have been prepared. Core from the J. Williams #4 well has been described and analyzed in order to determine the depositional environment, lithologic facies, and mineralogy, and their relationship to porosity. Vshale values have been calculated from gamma ray logs in each well, and the calculated Vshale data have been incorporated into a 3D model to help determine likely correlations within the reservoir. Porosity values calculated from neutron, density, and more modern FDC-CNL logs have been calibrated to core porosities. About 15 % of the porosity logs were omitted from the 3D modeling dataset because of erroneous values generated by the "neutron gas effect". Initial 3D models of both Vshale and porosity were prepared for Manlove. Cross-sections and interval slice maps have been prepared to visualize the heterogeneity of the reservoir.

The study of Herscher Field and its nearby satellite at Herscher Northwest Field has been the main focus of the investigation in the last year. Digitized well logs from approximately 250 wells have been correlated and used to make cross-sections, map the structure and model the porosity in the reservoir horizons in these fields. The Mt. Simon reservoir occurs at a depth of about 2240 ft in doubly plunging anticlinal closures that lie on trend with each other with a north-northwest axial orientation. Core analyses from six wells have been used to calibrate porosity calculations. Because of the pronounced "gas effect" seen in the GR-Neutron logs, neutron counts were not used to calculate reservoir porosity. A Vshale-Porosity transform was developed instead. 3D porosity models have shown that the basal Elmhurst sandstones as well as the upper Mt. Simon sandstones are effective reservoirs in Herscher Northwest field. The Elmhurst sands become more shaley to the southeast and do not play as significant a role in the main Herscher Field. Although sandstone beds in the Mt. Simon can be identified on the logs, neither they nor their interbedded shales can be correlated across the field. Thus, the shales probably form baffles rather than bound discrete sandbody layers. Both the Elmhurst and Mt. Simon sandstones are porous and friable with little cementation. Finer-grained sandstones contain abundant k-spar and quartz grains, whereas the more common coarse-grained sands contain primarily quartz grains and have abundant primary porosity.

Introduction

The Illinois State Geological Survey (ISGS) (an affiliated agency of the University of Illinois) is studying the Cambrian Mt. Simon Formation and gas storage reservoirs that occur in this formation in the northern half of Illinois. Detailed reservoir characterization studies and 3D models of porosity and Vshale are being prepared for the Manlove and Herscher Fields (Figure 1), fields nominated by the two companies that are supporting this study under an industrial affiliates program organized through the University of Illinois. These studies will improve the geological understanding of reservoir gas injection and production, and can be used at a later time to prepare reservoir fluid flow simulation studies for optimal field management. In addition, regional structure mapping of the Maquoketa Shale, Galena-Platteville Group, and Mt. Simon Sandstone in northern Illinois will outline potential new gas storage reservoir locations.

Results and Discussion

In the past year we have been assembling and loading Herscher field data and have built the 3D maps and models of Herscher field with a suite of Landmark Graphics software consisting of Openworks, Z-map, Petroworks and Stratamodel. In addition, we have picked formation tops in over 9000 wells located in northern Illinois for our regional maps, entered them into a database, and are presently quality checking the tops in these wells for accuracy. This year we completed a petrographic study of a second long core in the Manlove Field and samples from Herscher Field.

Manlove Field

Work on Manlove field was largely completed the previous year. The type log (Figure 2) shows the Mt. Simon Sandstone reservoir below the Eau Claire Formation seal. Petrographic study of core from that field has continued with the examination of thin sections from the Hazen #5 well. A student intern completed point counting of the slides to quantitatively determine the composition of the rock. Several of the samples in this well also were examined with SEM.

Petrographically, the reservoir sands at Manlove Field consist of clean, well-sorted quartz grains cemented by quartz overgrowth silica cement (Figure 3a). Pores are large and smoothly lined by this cement. Finer-grained sands and less well-sorted sands contain significant unaltered K-feldspar grains (Figure 3b), the content of which increases with decreasing average grain-size (see Table 1 below).

Table 1. Average feldspar content in Manlove Field Mt. Simon sandstones (based on modal analysis of 300 points per thin-section slide)

Grain Size	Feldspar Content
coarse ss	2.35%
med-coarse	6.00%
med ss	7.23%
med-fine ss	15.67%
fine ss w/ sh	21.33%

SEM images of the reservoir sands (Figure 4a) illustrate the euhedral quartz overgrowths and the open pore system. Clay minerals (Figure 4b) are sparse and composed of diagenetic illite.

Herscher and Herscher Northwest Fields

At Herscher Field and its companion field, Herscher NW, all logs have been digitized and entered into the Landmark program. Formation and internal reservoir marker bed picks have been made. Detailed correlations have been drawn and both structure and isopach maps have been made; both Vshale and porosity have been calculated. The final step will be to model the porosity of the field in three dimensions.

The Herscher Field/Herscher NW Mt. Simon reservoir lies at a depth of about 2200 feet. The type log (Figure 5) shows the Mt. Simon sandstone beds and some thin sandstones in the basal member of the Eau Claire, called the Elmhurst Sandstone, both of which are reservoirs in the Herscher NW field. The Elmhurst sands pinch out to the southeast and lack reservoir quality at Herscher.

Structure maps of the Herscher fields were constructed using the shallow Ordovician Galena (Trenton) limestone (Figure 6) and then a prominent marker in the deeper Elmhurst Member near the base of the Cambrian Eau Claire Shale (Figure 7). The shallow structure map includes data from numerous test holes drilled in the area to delineate the shape and attitude of the Herscher Anticline. The fold is a doubly plunging, asymmetric anticline with the steeper flank on the west and southwest and a more gentle flank on the east. Closure at the Galena (Trenton) level is about 90' at Herscher NW and about 50' in Herscher. At the deeper Elmhurst marker (Figure 7), structural closure at Herscher NW is reduced to about 70' and at Herscher to 50 to 70'. The southeast closure along the anticline axis at Herscher was not well defined in this study, but is not a field-limiting factor. A 3D view of this field (Figure 8) illustrates the reservoir level well control and the configuration of the lower Mt. Simon shale correlation marker. The Mt. Simon reservoir sands at Herscher NW field are structurally about 100' higher than those at Herscher field (see Figure 10).

Stratigraphic cross sections with the top of the Elmhurst Sandstone as a datum indicate the vertical and lateral variation of the reservoir sandstones. The Elmhurst which contains reservoir sandstone beds in Herscher NW, becomes more shaley over Herscher in Section A-A', a northwest to southeast oriented view (Figure 11). In Herscher NW, (Figure 12) these sandstones are 2 to 8' thick and separated by thin shales. The Mt. Simon in Herscher NW and in Herscher consists of massive sandstone beds, 15 to 30' thick. Subtle indentations in the GR log suggest that these thick sandstone beds are composed of stacked thinner sandstone units. Other than the two shales indicated on these cross-sections, correlation markers within the upper Mt. Simon cannot be traced across the field. In Herscher Field (Figure 13), the Elmhurst sandstones are considerably more shaley than in Herscher NW. The Mt. Simon contains thick, multiple, stacked sandstone beds of reservoir quality. As in Herscher NW, thin shale beds other than the indicated correlation markers cannot be readily correlated across the field. Thus, the shales act as baffles rather than compartment barriers.

Herscher/Herscher NW field modeling is less well constrained than at Manlove, but still provides insight into reservoir continuity and geometry . Only six wells have reservoir core data, two wells have FDC-CNL logs, while the remaining wells have only 1960s vintage gamma ray-neutron logs. Many neutron logs were useless for neutron porosity determination due to “gas effect”. An alternative modeling approach is to develop a Vshale-porosity transform (Figure 14). A 3D porosity model (Figures 15a and 15b) developed from the Vshale porosity indicates more laterally continuous sandbodies than at Manlove, although vertical continuity remains fairly poor. Thus, the internal shales may provide baffles rather than discrete fluid flow compartments.

Cuttings from wells in Herscher and Herscher NW fields were used to characterize the petrography of the reservoir rocks (Figures 16 and 17). No core samples were available. Binocular examination of loose cuttings and thin-sections of cuttings revealed that both the Elmhurst and Mt. Simon sandstones were more porous and friable than the Mt. Simon sandstones at Manlove Field. Loose, rounded quartz grains of coarse grain-size were abundant in Herscher well cuttings. They were frosted or had small quartz overgrowth facets, indicating minor amounts of silica cement. Grains of feldspar were common in cuttings chips, especially in fine-grained sandstones and the fine fraction of bimodal (fine and coarse-grained) sandstones. Stains applied to the thin-sections (Figure 17) indicated that the feldspar was of the K-feldspar variety. The feldspar grains had sharp edges and little cloudiness indicating that they were unaltered to clay. Diagenetic clays in pores were not observed in the sandstones. Thus, porosity appeared to be comprised of primary, unfilled voids that were present when the rock was deposited. This is in contrast to the Mt. Simon at Manlove Field where the rock is buried 2000 feet deeper and contains more silica cement, more altered feldspar, minor diagenetic clay, and more secondary pores.

Regional Mapping

Data from all significant wells drilled in the northern half of Illinois have been compiled in order to create regional structure maps of the tops of the Ordovician Maquoketa Shale, Ordovician Galena (Trenton) Limestone, the Cambrian Eau Claire Shale, and the Mt. Simon Sandstone. The region covered by the database comprises the prime potential area for developing new gas storage sites that could feed the Chicago market . A pallistering technique that adds the isopach from the overlying marker bed, such as the Maquoketa Shale or Galena (Trenton) formation to the top of the Mt. Simon interval, to the structure map of the shallow marker will be used to create a map of the Mt. Simon structure. This technique is also called, “conformable mapping”. Picking of up to 8 regional formation tops in all wells of northern Illinois has been completed, but the number of deeper formation penetrations decreases sharply below the Galena (Trenton). The database containing these log tops comprises over 9000 wells. The final review of this data for accuracy is being made using preliminary contoured isopach and structure maps, such as the top of the Galena/Trenton (Figure 18) to identify and correct the wells where contour bulls eyes occur.

Approaches for final fiscal year:

We will make one more pass to refine our detailed reservoir model for Manlove Field using Landmark’s StratWorks, Petroworks, and StrataModel software. A key element for this will be to determine the proper porosity value to use. In Manlove we have calibrated the log data to the core data for the 35 wells having core data, and are currently reviewing calibration and normalization of the old neutron porosity logs to refine the model illustrated in last year’s report. Modeling at Herscher has been completed and will not be revisited. We will make final adjustments for Manlove Field so that the resulting porosity model is smooth between wells. We will examine the Vshale distribution with StrataModel to look for additional correlation markers within the Mt. Simon at Manlove.

Quality check maps of the regional formation data collection should be completed shortly and then final structure maps will be prepared.

Finally, all the data from the two field studies and the regional data will be compiled into the final technical report. This report in .pdf format along with digital log files, map grids, and other model information will be submitted to DOE on CD-ROM.

The following summary table indicates our progress on project tasks and the anticipated work schedule:

Task	Sub-tasks	% Accomplished (as of 9/31/02)	Months from Start			
			FY00	FY01	FY02	FY03
			3 6 9 12	15 18 21 24	27 30 33 36	39 42
1. Data Collection & Preparations	Collect well, core & report data from contributing companies	100%	xxxxxxxxx	x		
	Digitize basal Knox through Eau Claire & Mt. Simon intervals from paper wireline logs, as needed	100%	xxxxxxxxx	xx		
	Prepare necessary core data on spreadsheets	100%	xxxxxxxxx	x	xxx	
	Normalize GR & F logs	100%	xxxxxxxxx	xxxxxxxxxx	x	
	Enter all digitized well logs & data into Landmark software	100%	xxxxxxxxx	xxxxxxxxxx	xxx	
	Identify, describe and sample cores	95%	xxxxxxx		xx	
2.Regional Geologic Mapping & Sediment Facies Description	Make sed facies description including thin section, SEM & XRD analyses	95%		xxxxxxxxx	xxx	x
	Correlate well logs, picking formation & sub interval tops	95%	xxxxxxxxx	xxx	xxxxx	xx
	Make key stratigraphic and structure cross-sections for selected fields	95%	xxxx		xxx	xxx
	Make structure & isopach maps for region & selected fields.	85%	xxx	xxxxxxxxxx	xxxxx	xxxxx
	Make regional aquifer salinity map	30%			xxx	xxx
3.Petrophysical Characterization & Model Developments	Make Cross-plots of core porosity, core permeability, & sedimentary facies for each field	90%			xxx	xxxx
	Make 3D model of reservoir porosity	90%			xxxxx	xxxx

	and Vshale for each field					
4. Technology Transfer	Formation of technical advisory committee consisting of one member per sponsoring gas company, DOE and ISGS	100%	x			
	Prepare annual progress reports	100%	x	x	x	
	Conduct meetings with technical advisory committee	80%	x	x	x	x
	Prepare one technical article and presentation abstract submitted to a national technical forum (AAPG or SPE)	50%	x			x
	Prepare and conduct regional workshops (PTTC and SPE Midwest Gas Storage Chapter)	50%	x x			x x
	Submit final project report	30%				xxx

Conclusions

The Mt. Simon Gas Storage Reservoir Characterization is progressing well as noted in the table above. The technical products (maps, petrography, models, etc.) should be completed by April 2003, leaving the remainder of the project time to prepare the final technical report, compile all the data and develop workshop course materials.

The study at Manlove field is the furthest along, primarily because digital logs were provided to ISGS by the field operator. Maps, cross-sections, one core description and initial 3D models of Vshale and porosity have been prepared. The only revision will be to recalibrate porosity values in a few wells in order to eliminate vertical striping in the model.

At Herscher field the 3D porosity model had to be calculated from the Vshale value. Neutron porosity values were unsatisfactory because of the pronounced “gas effect” seen in these logs. Furthermore, calibration was difficult because there were core data from only 6 wells and the data were highly scattered.

Herscher NW field has gas storage in the basal Elmhurst sandstones as well as the underlying Mt. Simon. These Elmhurst sandstones pinch out to the southeast and are not seen at the main Herscher Field. Both the Elmhurst and Mt. Simon sandstones are porous and friable with little cementation. Finer-grained sandstones contain abundant k-spar and quartz grains, whereas the more common coarse-grained sands contain primarily quartz grains with abundant primary porosity.

The regional mapping database now contains over 9000 wells, including all the 879 Mt. Simon penetrations known in northern Illinois. The data are being examined in isopach and structure maps to identify and correct errors. Conformable mapping will be used to generate a projected regional Mt. Simon structure map that will identify leads for additional storage sites. A draft of the top Galena/Trenton structure map is included with this report.

List of acronyms and abbreviations

FDC-CNL- Compensated Formation Density and Compensated Neutron Log
GR- Gamma Ray Log
ISGS- Illinois State Geological Survey
U of I- University of Illinois
Vshale- A calculated shale volume based on the Gamma Ray log

References Cited

Willman, H.B., E. Atherton, T. C. Buschback, C. Collinson, J. C. Frye, M.E. Hopkins, J. A. Lineback, A. A. Simon, 1975, Handbook of Illinois Stratigraphy: Illinois State Geological Survey Bulletin 95, 261p.

Nelson, W. J., 1995, Structural Features in Illinois: Illinois State Geological Survey Bulletin 100, 144p.

Abstract of Poster Presentation Accepted by AAPG for May 11-14, 2003 Annual Meeting in Salt Lake City, Utah

Data Constraints in 3D Reservoir Characterization of Mt. Simon Sandstone Gas Storage Fields

Morse, David G. and Hannes E. Leetaru, Illinois State Geological Survey, Champaign, IL

In northern Illinois the Cambrian Mt. Simon Sandstone is a permeable and porous formation that is used for gas storage by the utilities in the state. This U. S. Department of Energy study evaluated the Mt. Simon in Manlove Field, Champaign County, Illinois and Herscher Field, in Kankakee County, Illinois, in order to improve knowledge of the reservoir character and geometry. The reservoir sandstone occurs at 3,900 feet in Manlove Field and 2,200 ft at Hersher Field. There are significantly more data available for a reservoir characterization study at Manlove than for Hersher field. The 3-D porosity model at Manlove Field is well constrained with porosity and permeability measurements from 35 cores and calculated porosity values from modern FDC-CNL logs run in half of the 170 wells in the field. The resulting 3D model indicates a heterogeneous reservoir with channel-confined, vertically discontinuous, high porosity compartments.

Herscher field modeling is less well constrained, but still provides insight into reservoir compartments. Only six wells have reservoir core data, two wells have FDC-CNL logs, while the remaining wells have only 60's vintage gamma ray-neutron logs, many of which were useless for neutron porosity determination due to "gas effect". An alternative modeling approach is to develop a Vshale-porosity transform. A 3D porosity model developed from the Vshale porosity indicates more laterally continuous sandbodies than at Manlove, although vertical continuity remains fairly poor. Thus, although well-constrained models are preferable, models built with older, less constrained data provide an improved understanding of the heterogeneous Mt. Simon reservoir geometry and potential flow units.

Abstract of Poster Presentation submitted to the Eastern Section AAPG for presentation at the annual Section meeting in Pittsburgh, PA, September 6-10, 2003

Characterization of the Mt. Simon Sandstone Gas Storage Reservoirs at Herscher and Herscher Northwest Fields, Kankakee County, Illinois

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Herscher Field in Kankakee County was originally an Ordovician-age Trenton oil field that was abandoned in the early 1900's. In 1952, the storage of natural gas for peak delivery to the Chicago market was begun in the Cambrian-age Galesville Sandstone. In 1956, storage of natural gas was begun in the underlying Cambrian-age Mt. Simon Sandstone and Elmhurst sandstone member of the Eau Claire Shale, which provided a better-sealed reservoir.

Geologic characterization of the Mt. Simon/Elmhurst reservoir at Herscher has been fraught with difficulty because of the lack of modern wireline logs. Core data from seven wells, and neutron and gamma ray curve data, the only wireline logs available, were used for petrophysical analysis. Most of the wells were drilled and logged after the initial storage of gas had begun; therefore, many of the neutron logs were influenced by the 'gas effect' and resulting calculated porosity values were too pessimistic. An alternative empirical methodology using Vshale to estimate porosity was used to improve models in gas effected intervals. Even this method does not fully capture the porosity variation seen in core for the cleanest sandstone. Nevertheless, three-dimensional modeling of the Mt. Simon/Elmhurst reservoir, using Vshale, shows shale interval baffles and porosity variation within the fields, but there are no laterally extensive shales that would vertically compartmentalize the reservoir. Methodologies used in this project can be applied to other gas storage reservoir characterization projects where data quality is an issue.

Graphic Materials

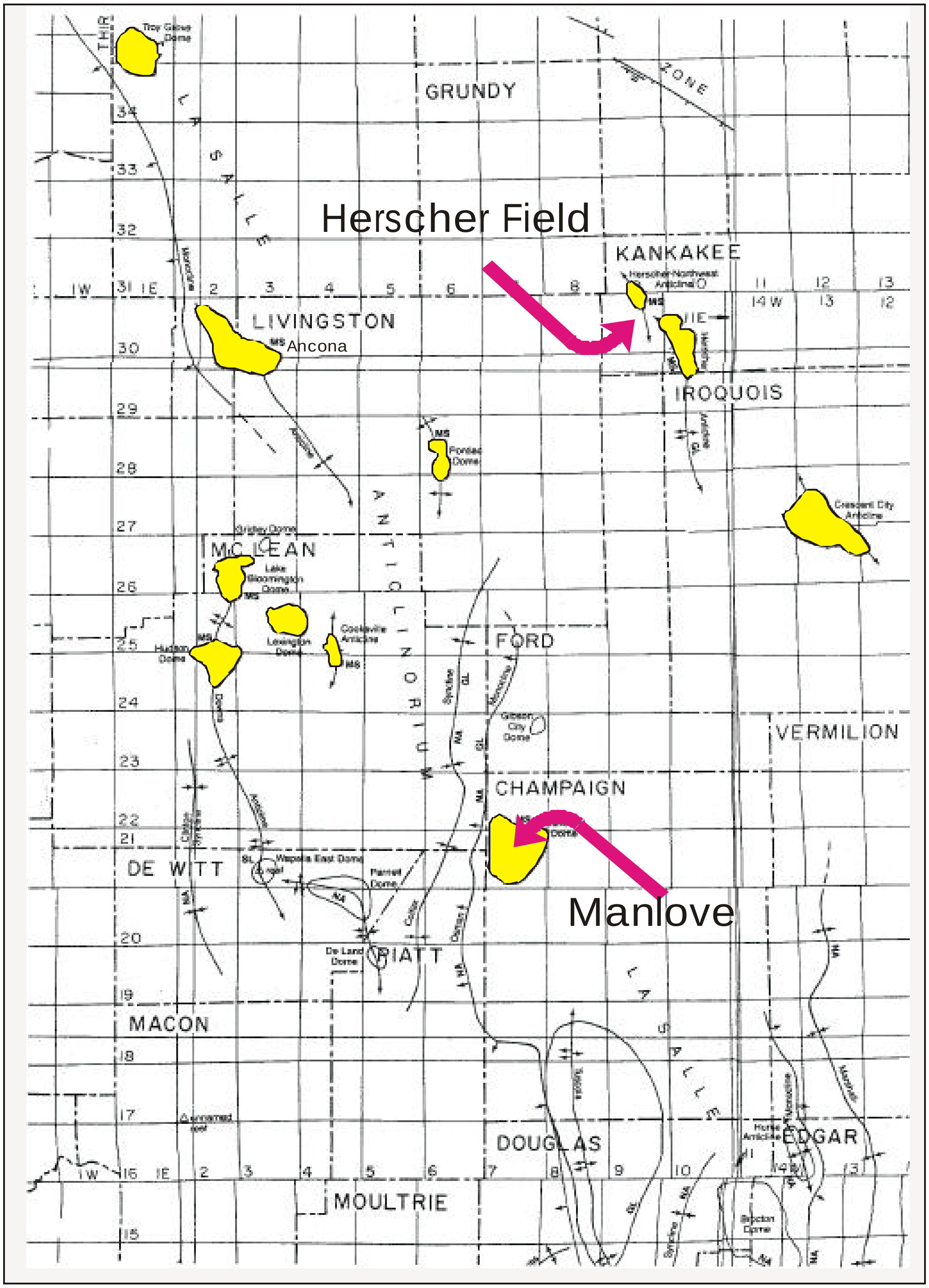

Figure 1. Structural features of North Central Illinois. Mt. Simon gas storage fields are shown in yellow.

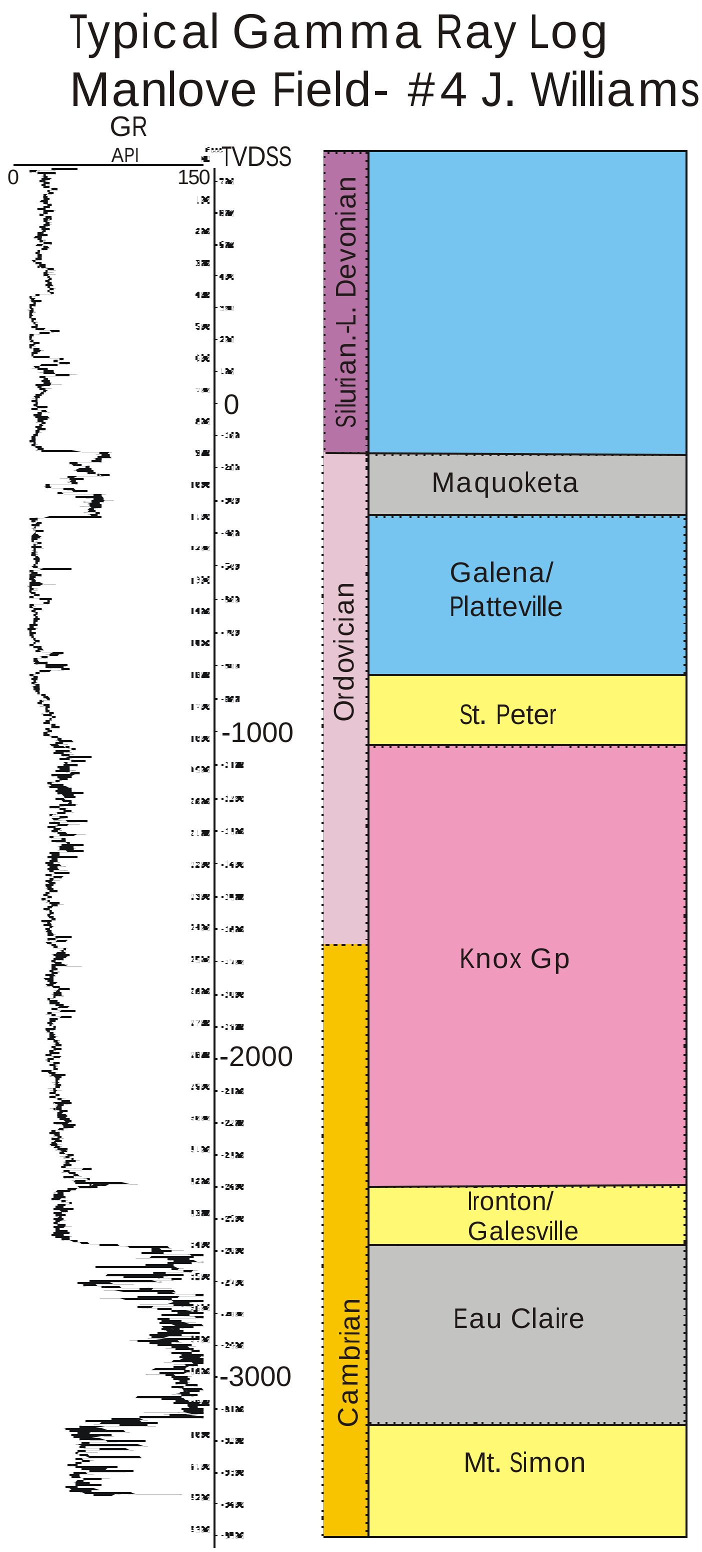

Figure 2. Gamma Ray log and Geologic Column from Manlove Field.

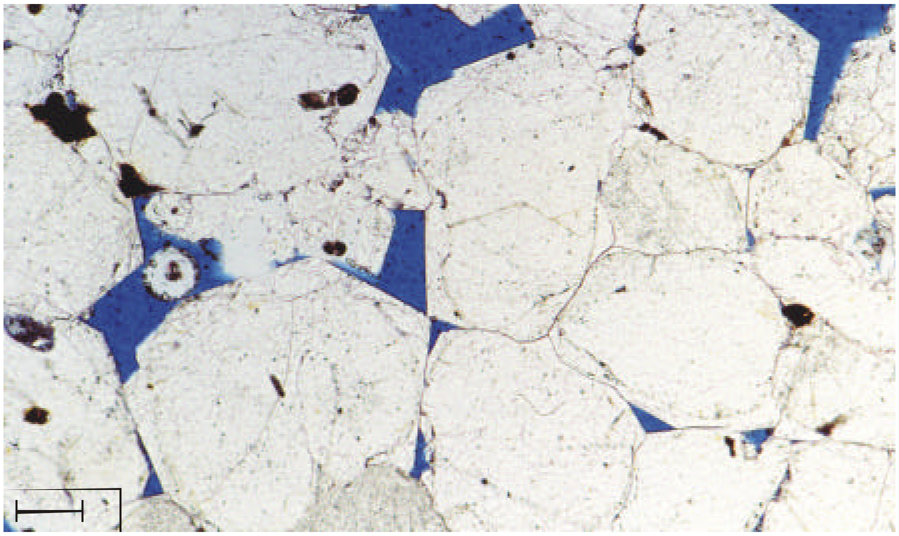

Figure 3a. Thin section of coarse-grained sandstone showing pronounced quartz overgrowths and clean open pores. J. Williams #4, 1234.7m (4051.0ft). Bar scale is 0.25mm

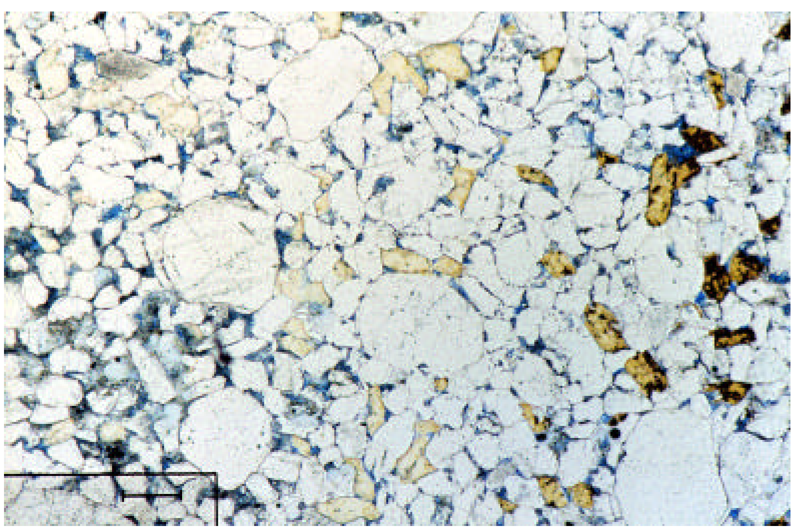

Figure 3b. Thin section of poorly sorted fine sandstone containing scattered coarse quartz grains. Yellow stained grains are k-feldspar. J. Williams #4, 1235.2m (4052.5ft). Bar scale is 0.5mm

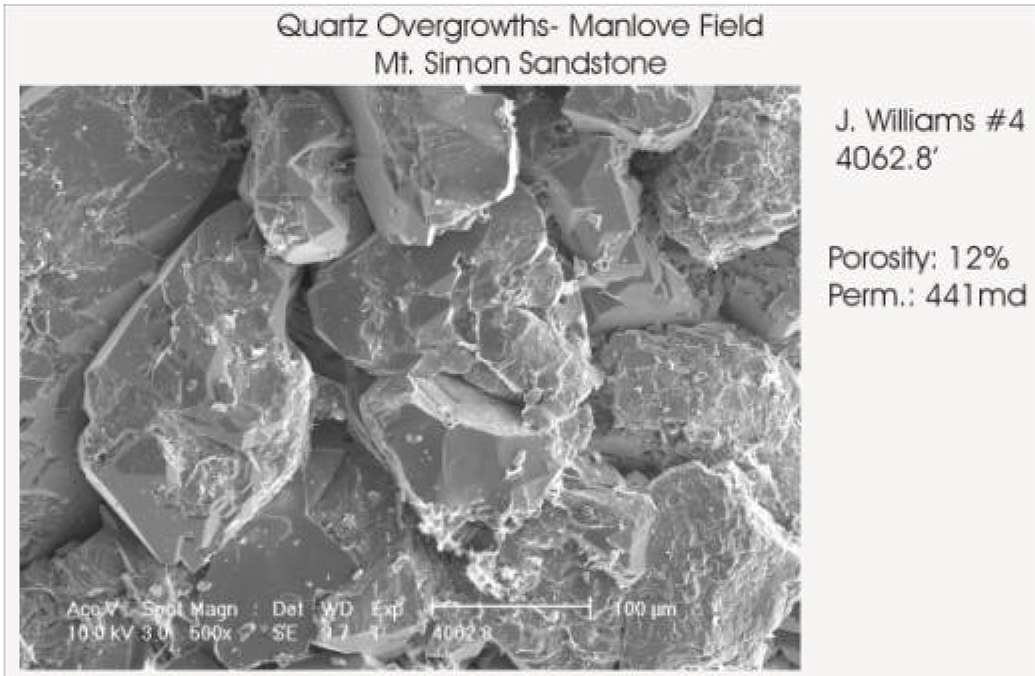

Figure 4a. SEM image of clean medium-coarse sandstone with quartz overgrowths. J. Williams #4, 1238.3m (4062.8ft). Bar scale is 0.1mm.

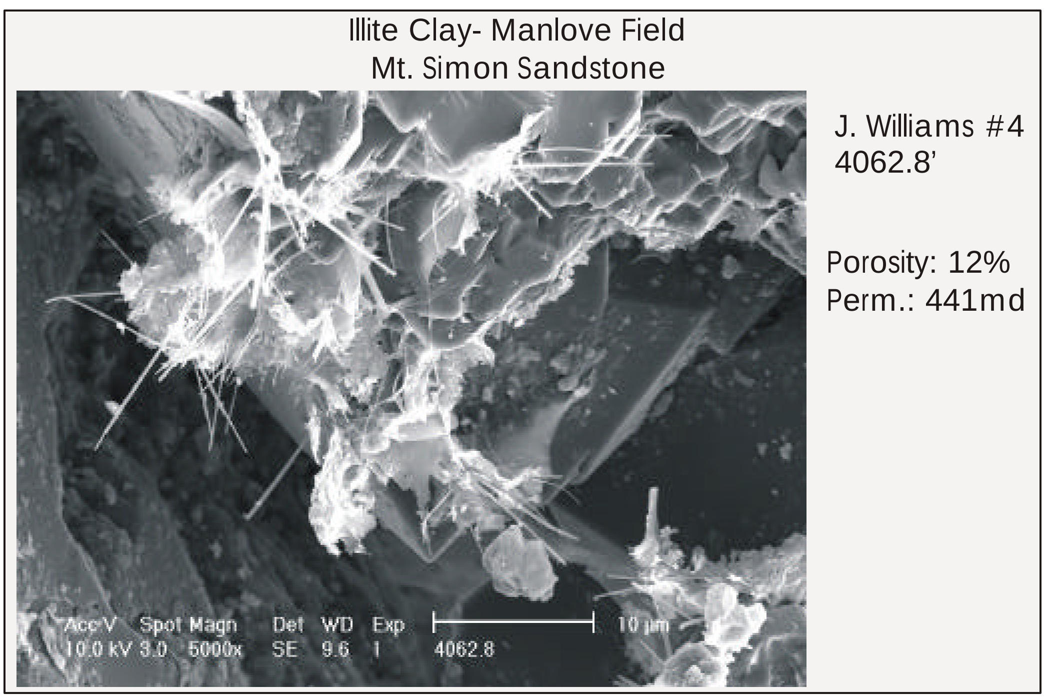

Figure 4b. SEM view of trace amounts of illite clay growing on a quartz overgrowth. J. Williams #4, 1238.3m (4062.8ft). Bar scale is 0.01mm.

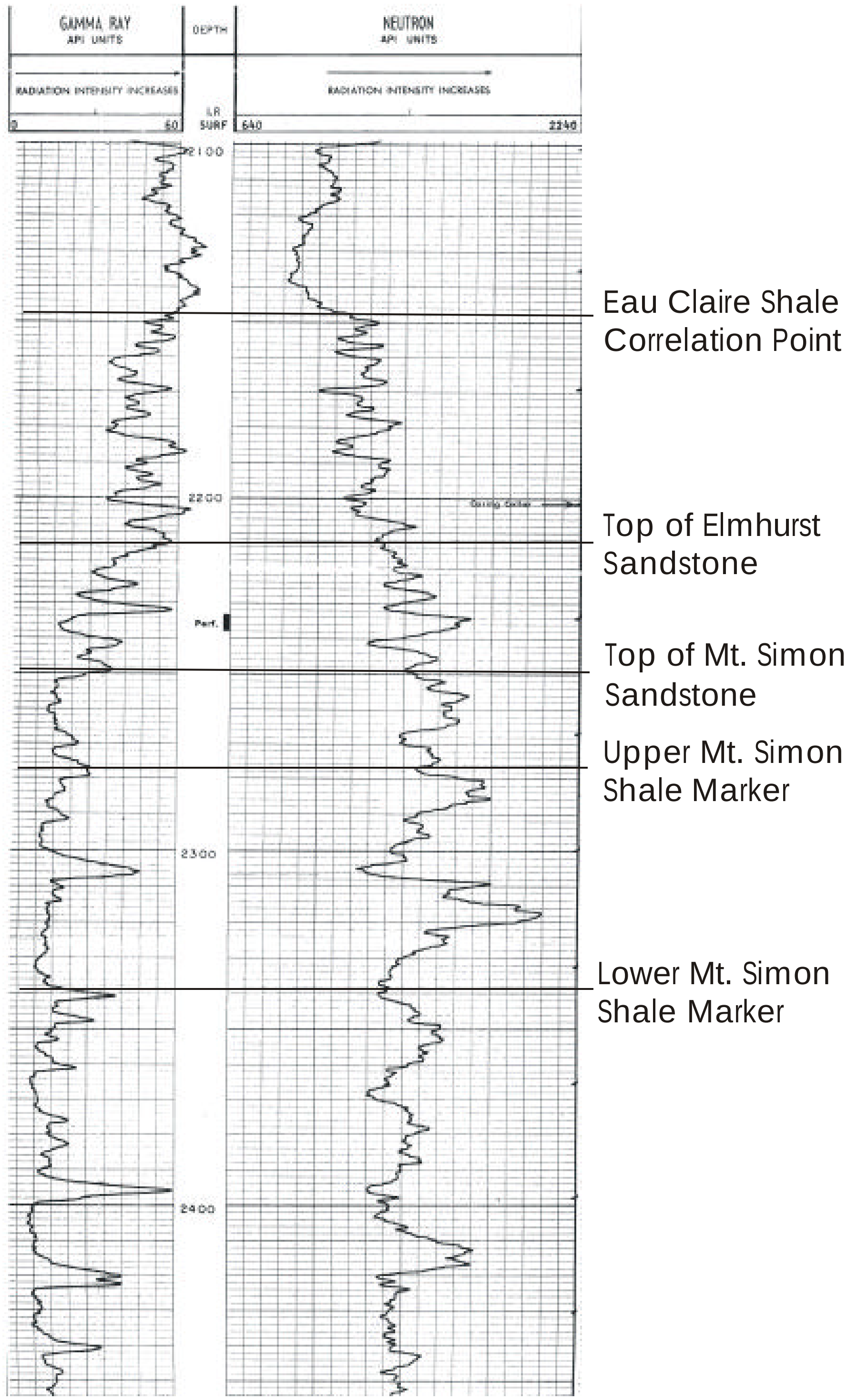

Figure 5. Type Log Herscher Northwest Field.
(Natural Gas Pipeline Co. of America, E. Oberlin #4, Sec 3, T30N, R9E, Kankakee Co. IL)

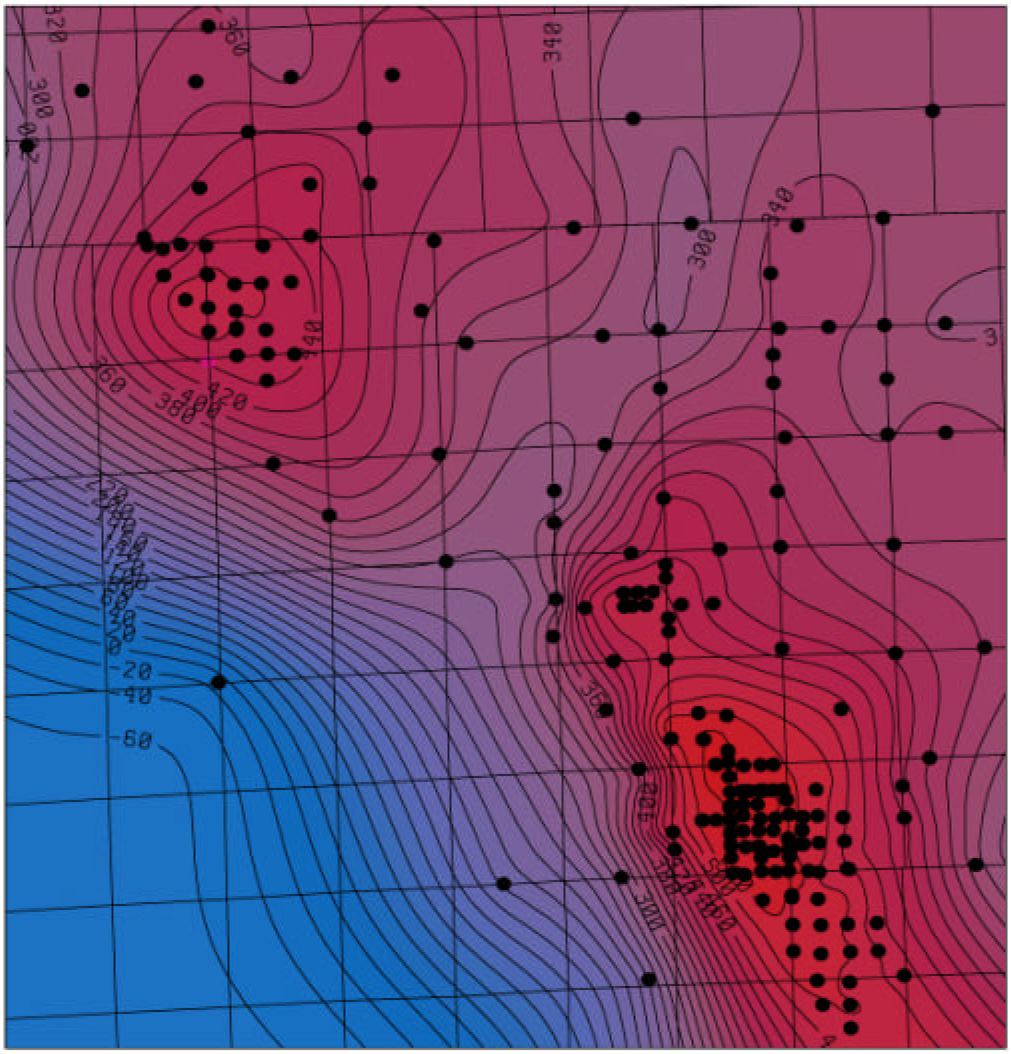

Figure 6. Structure contour map on the top of the Galena (Trenton) Limestone, Herscher and Herscher NW Fields. Contour interval is 20 feet. Mean sea level is the datum.

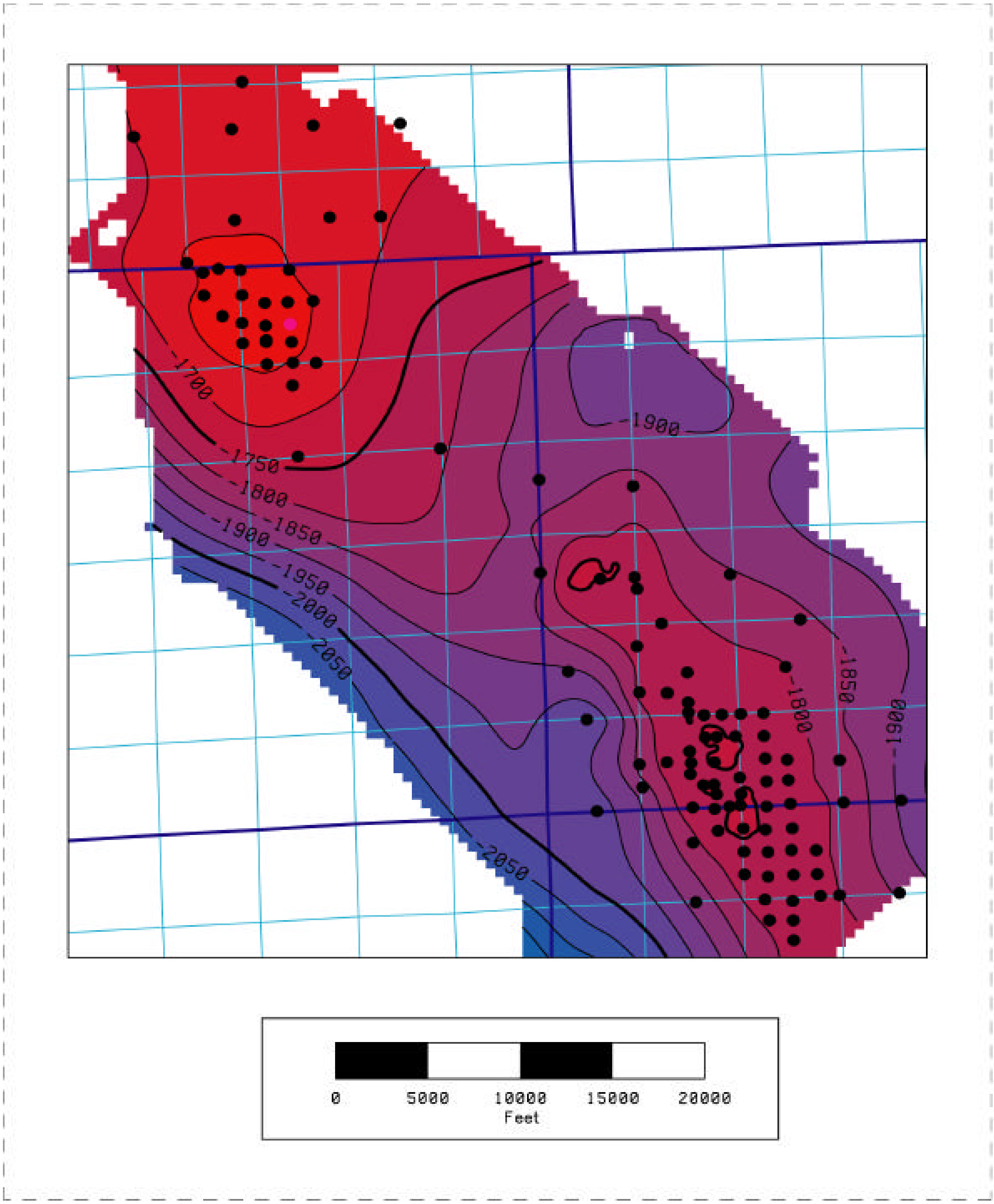

Figure 7. Elmhurst Marker structure map Herscher and Herscher NW Fields. Contour interval is 50'.

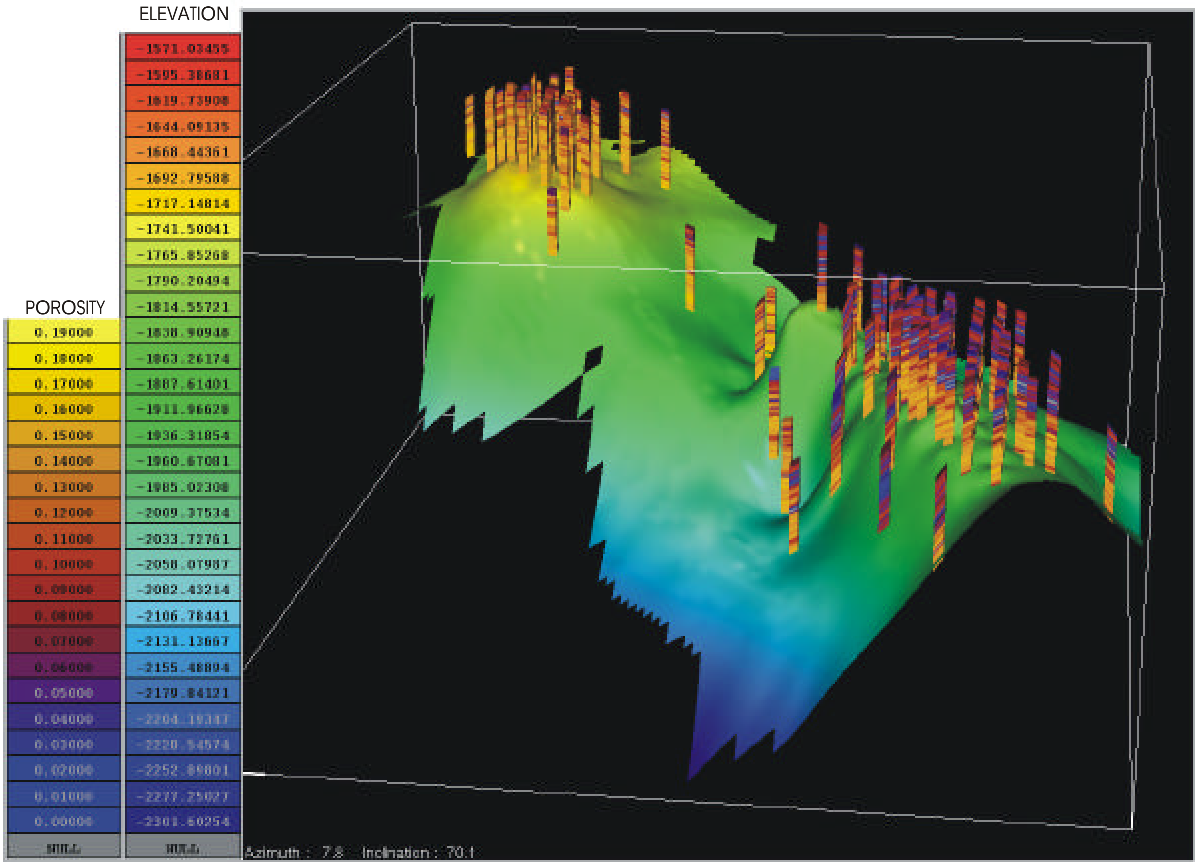

Figure 8. 3D view of Herscher and Herscher NW fields looking toward the north.

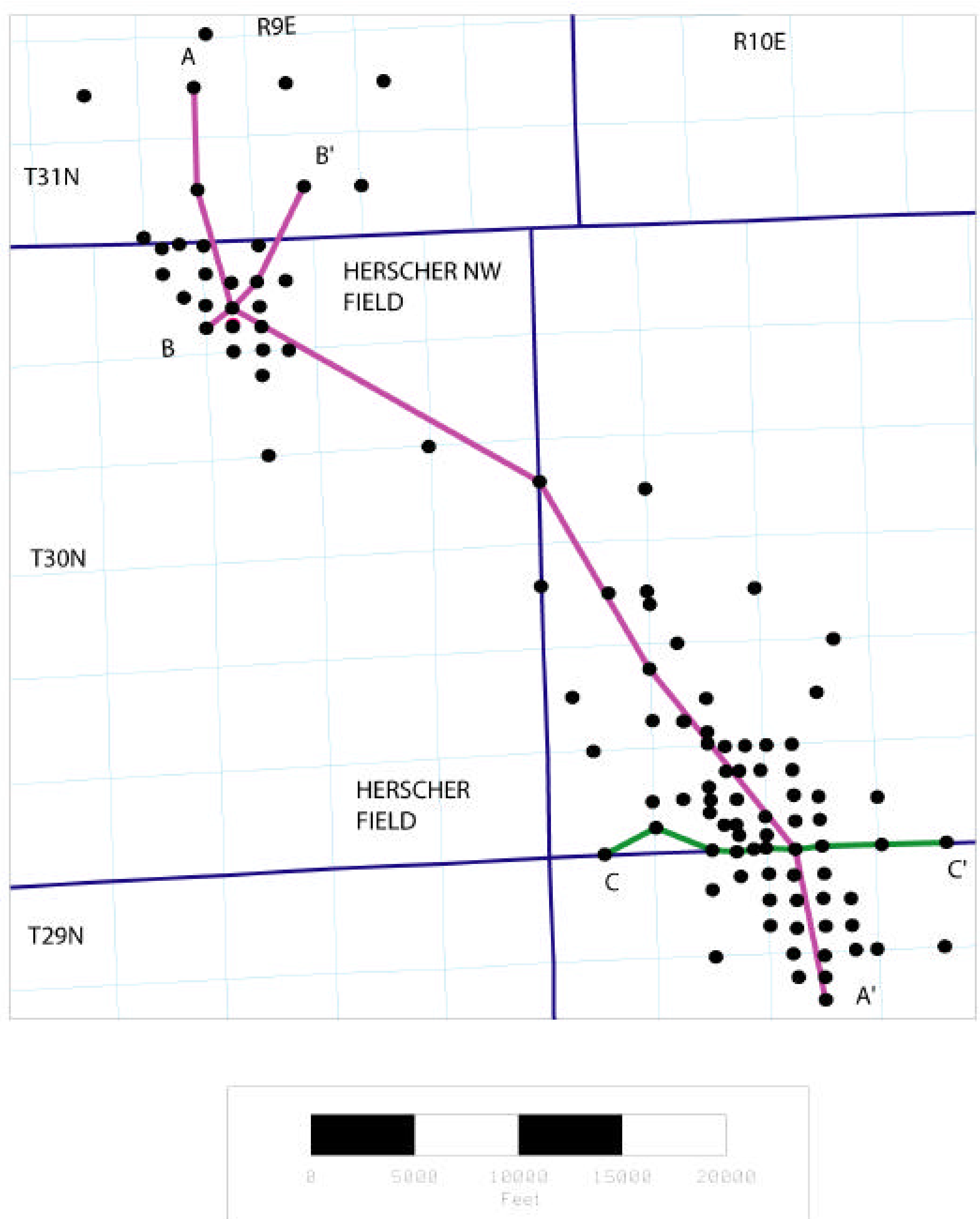

Figure 9. Index map for Herscher and Herscher NW Fields

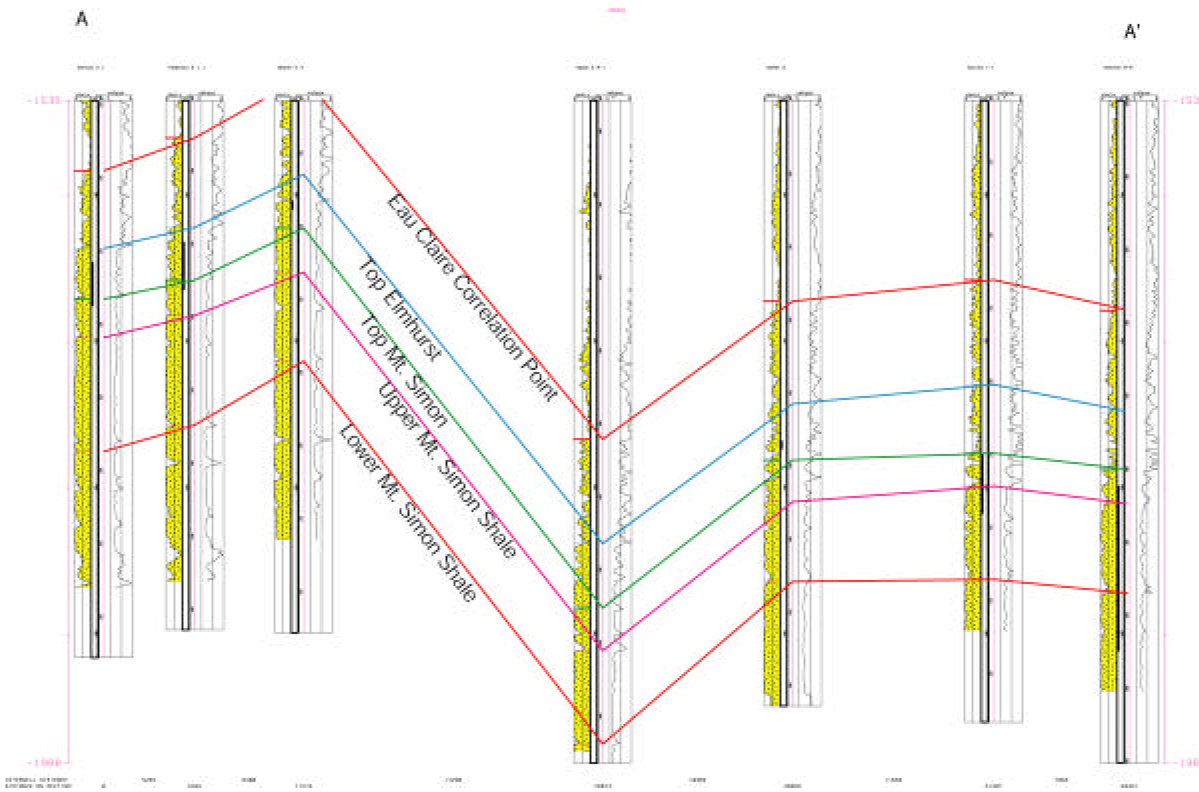

Figure 10. Structure cross-section A-A' of lower Cambrian strata, extending from north (A) to south (A') from Herscher NW to Herscher Field.

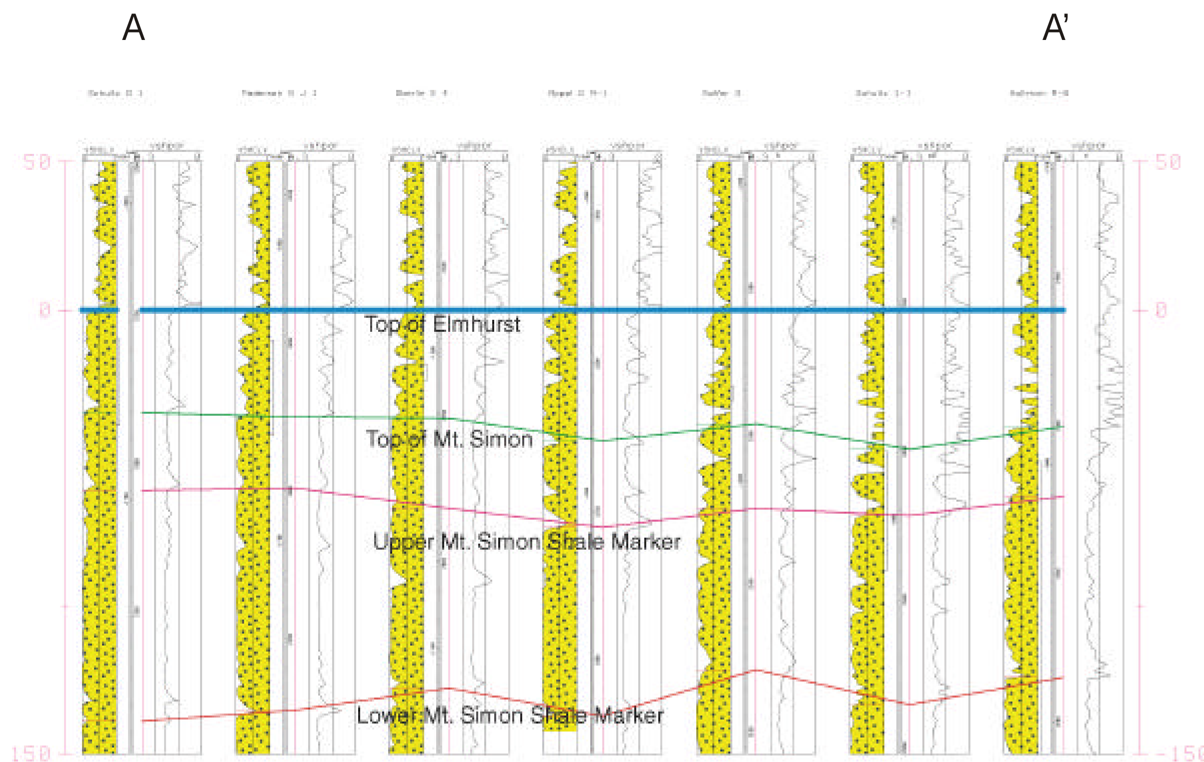

Figure 11. Stratigraphic cross section A-A' extending from north (A) to South (A') from Herscher NW to Herscher Fields. Datum is the top of the Elmhurst Sandstone.

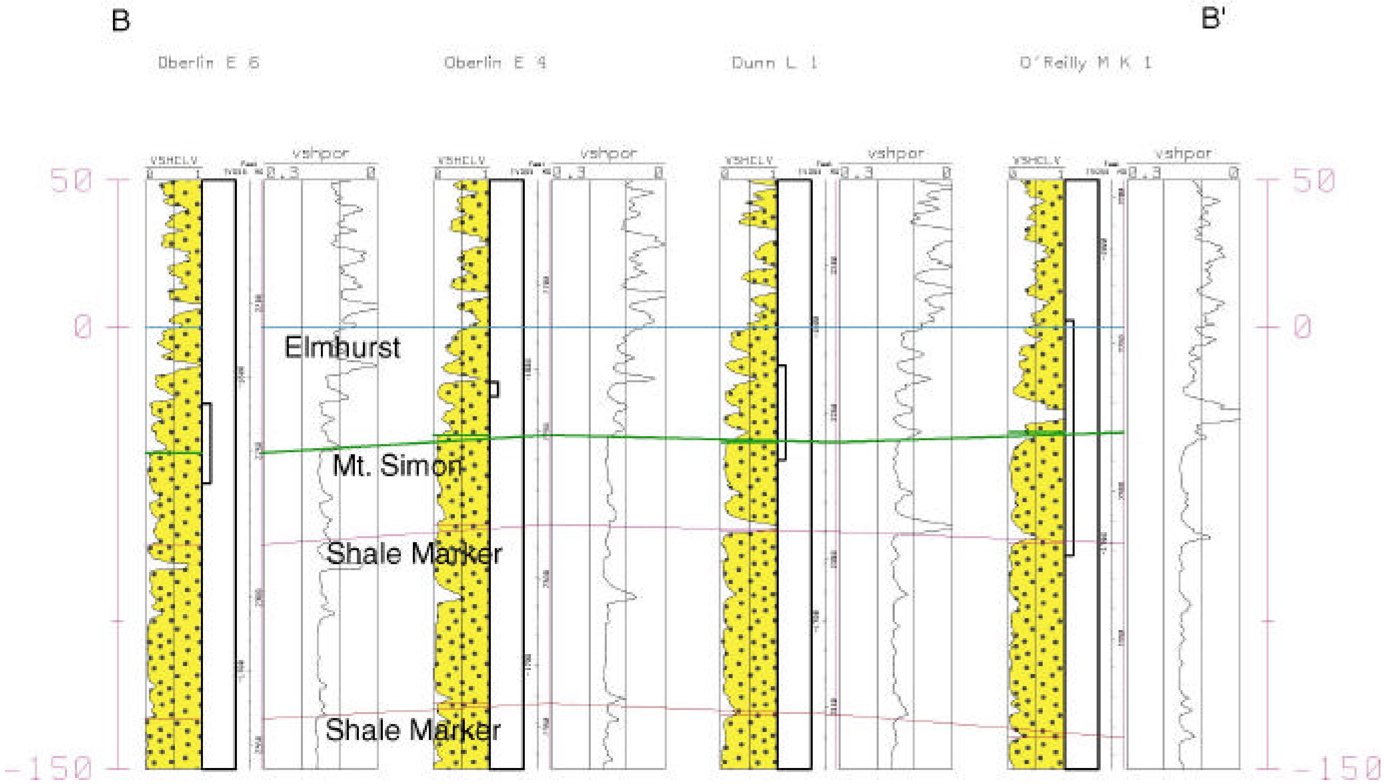

Figure 12. East-West stratigraphic log cross-section B-B', Herscher NW Field.
Datum is the top of the Elmhurst Sandstone.

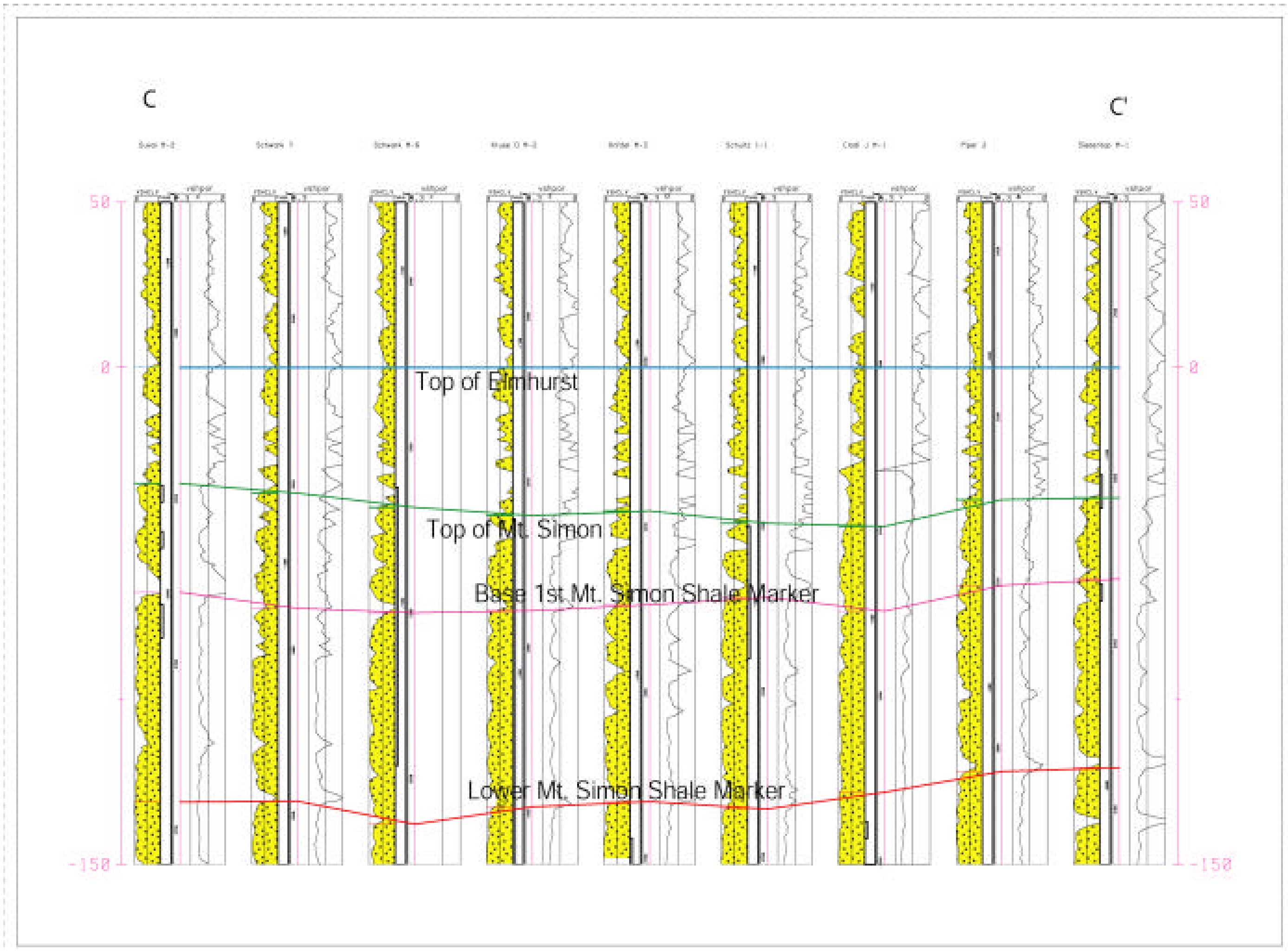

Figure 13. East-West stratigraphic cross-section C-C' across Herscher Field. Datum is top of Elmhurst Sandstone.

Vshale Linear

$$Vsh\_linear = (GR-Grmin)/(GRmax-GRmin)$$

Vshale Calvier

$$VSHCLV= 1.7-SQRT(3.38 - (Vsh\_linear + 0.7)^2)$$

$$Vshpor= 0.164 + (VSHCLV*0.168)$$

Figure 14. Vshale-porosity transform equations at Herscher and Herscher NW fields.

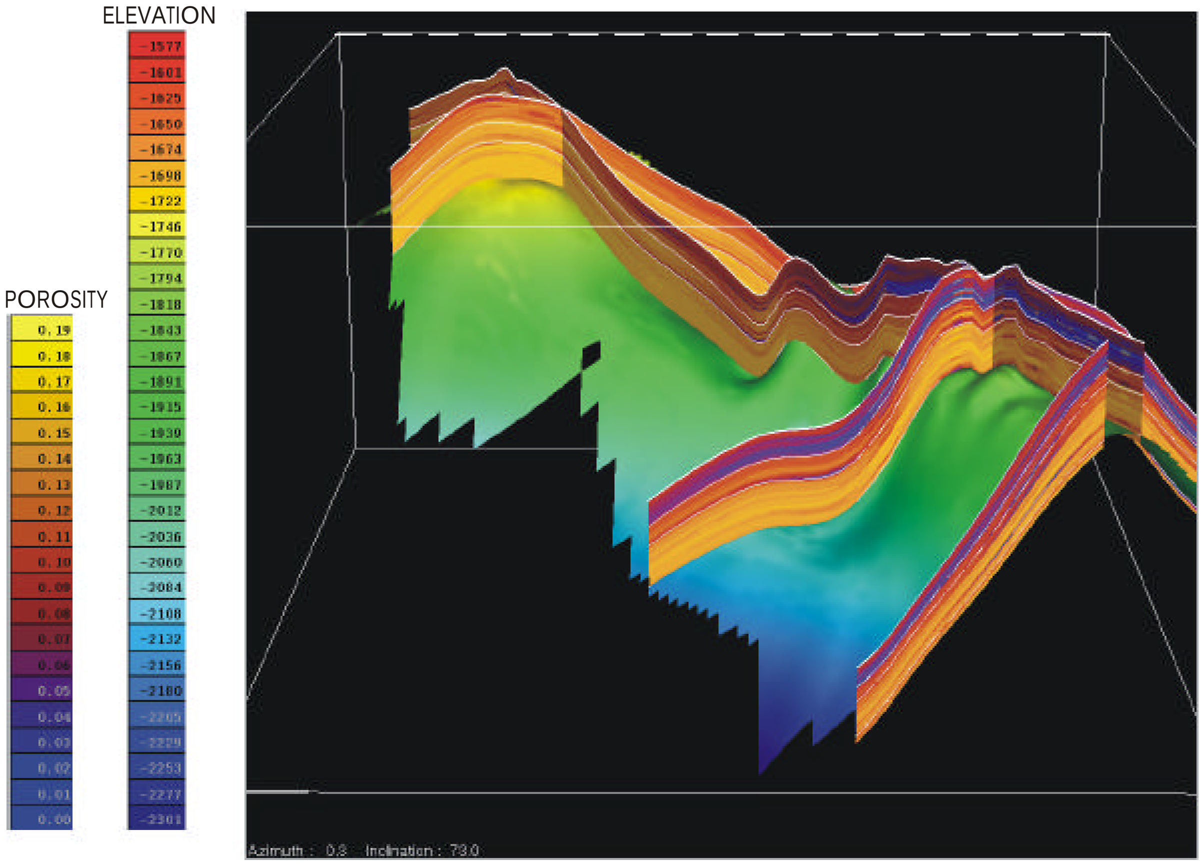

Figure 15a. Fence diagram of porosity in Herscher and Herscher NW fields. View is toward the north.

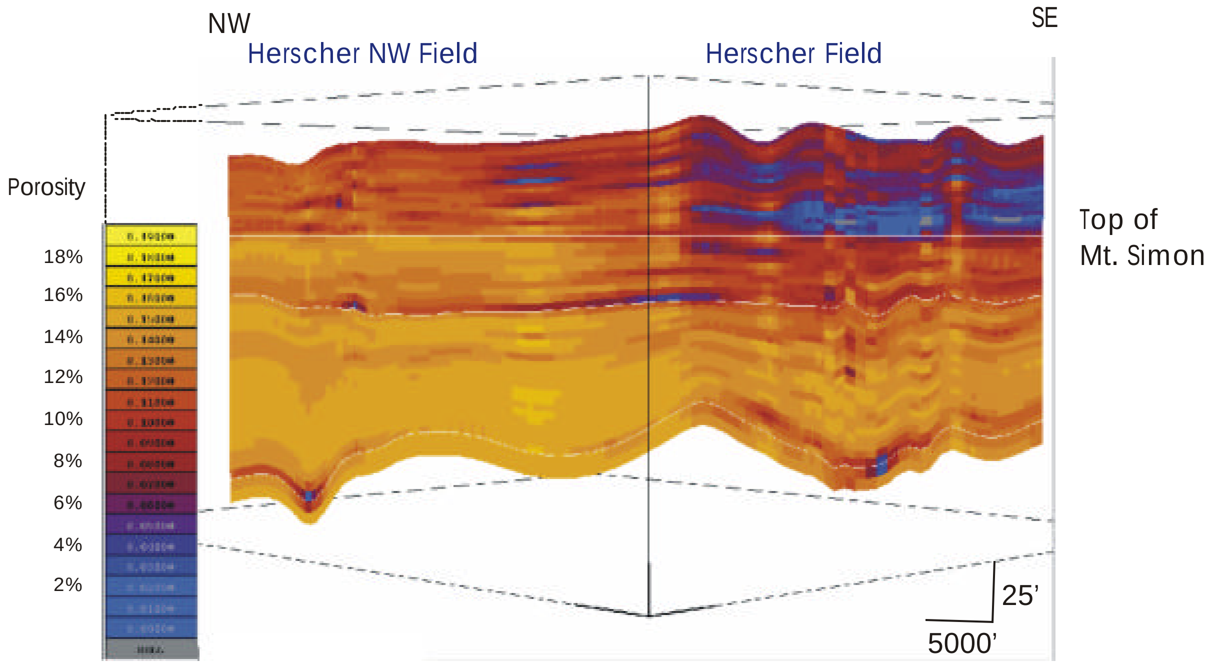

Figure 15b. North-west to South-east stratigraphic porosity cross section from Herscher NW to Herscher Fields. The datum is the top of the Mt. Simon Sandstone.

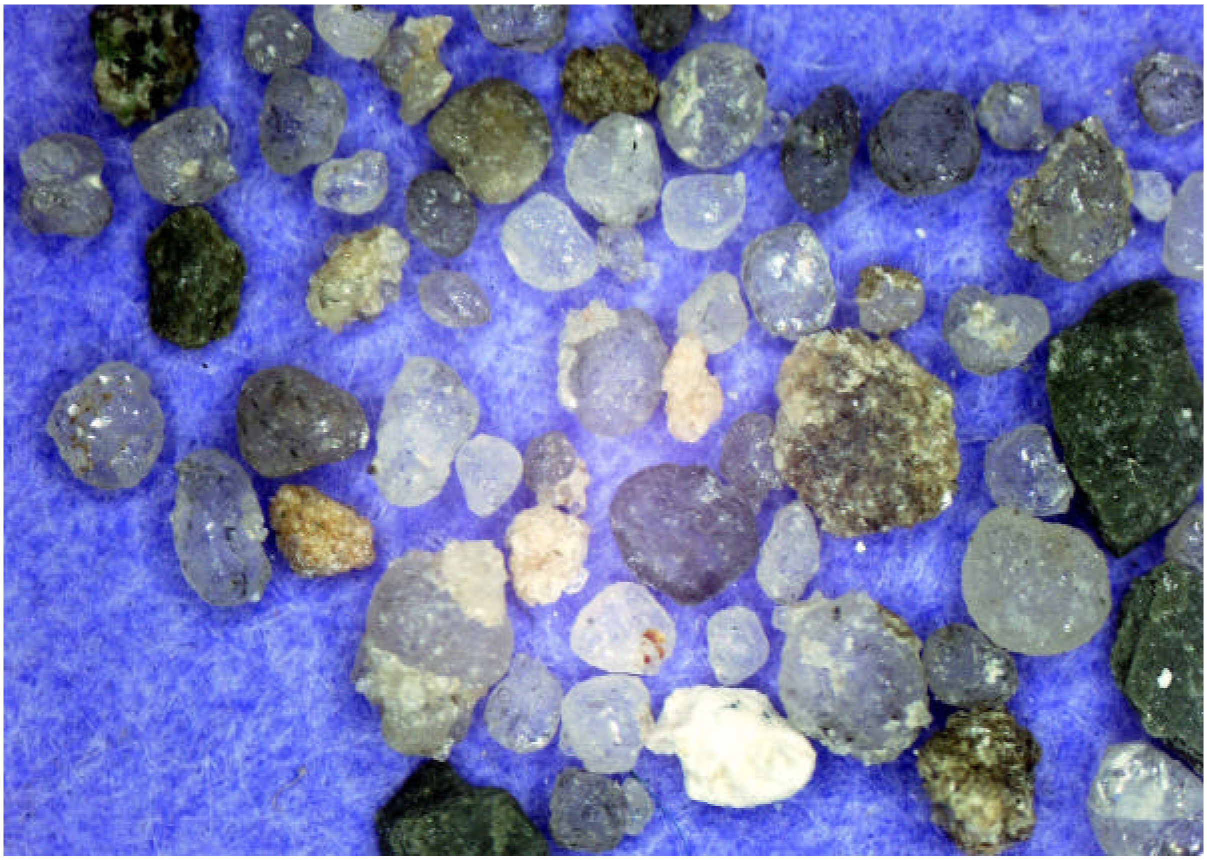

Figure 16a. Rounded coarse quartz grains from cuttings of the Elmhurst Sandstone at Herscher NW Field. Note that many of the grains have black dots on their surface. Grains with this feature has been described as "sooty" (Willman, et al, 1975, p.42), a characteristic of the Elmhurst. Cemented to a few quartz grains is a pinkish mineral believed to be k-feldspar. Dark gray shale and pure white fine-grained chert cuttings are believed to be cavings from overlying formations such as the Eau Claire Shale or the Knox carbonates. Field of view is approximately 8mm across. Sample from the Natural Gas Pipeline Co. of America, #1 L. Dunn (Sec. 3, T30N, R9E, Kankakee Co., IL), 2240'.

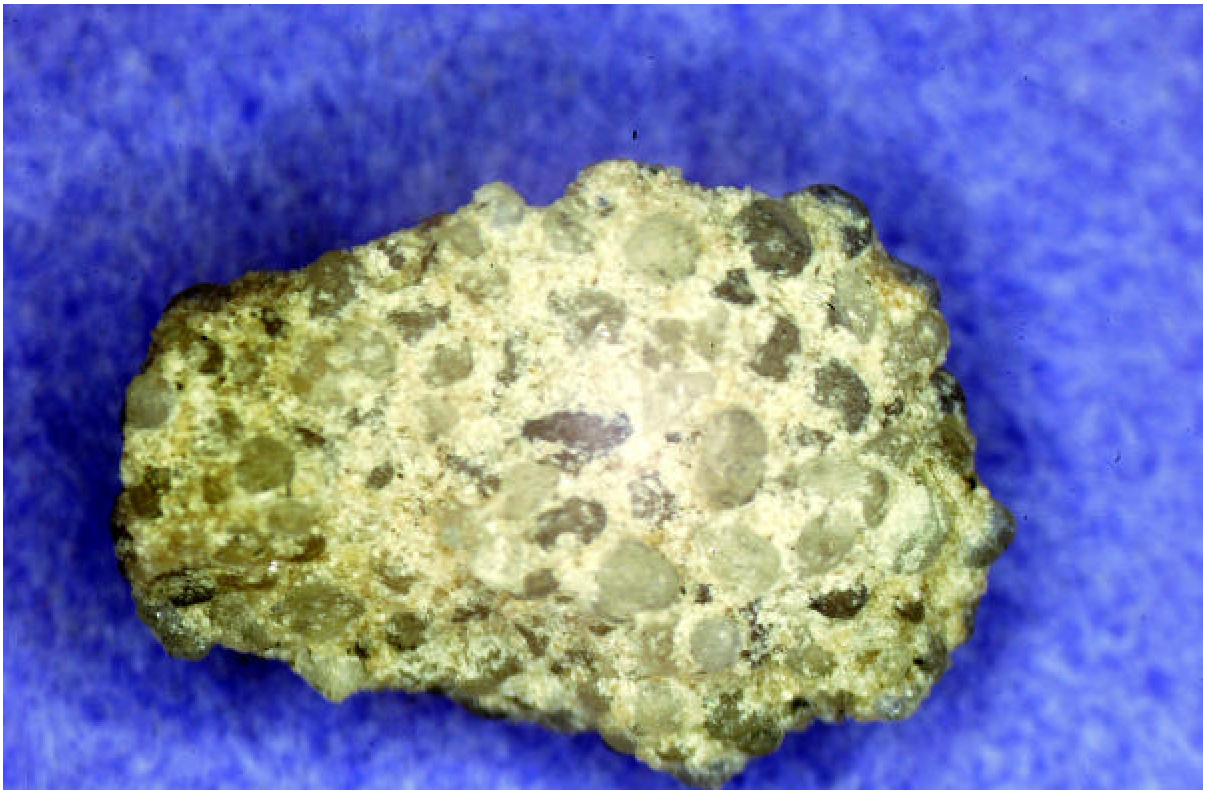

Figure 16b. Cuttings chip of the Elmhurst sandstone in Herscher NW Field. This sample is about 5mm across and exhibits medium to coarse, rounded quartz grains that are bound together by a finer granular matrix that is comprised of fine-grained quartz and feldspar. The chip is friable. Sample from the Natural Gas Pipeline Co. of America, #1 L. Dunn (Sec. 3, T30N, R9E, Kankakee Co., IL), 2240'.

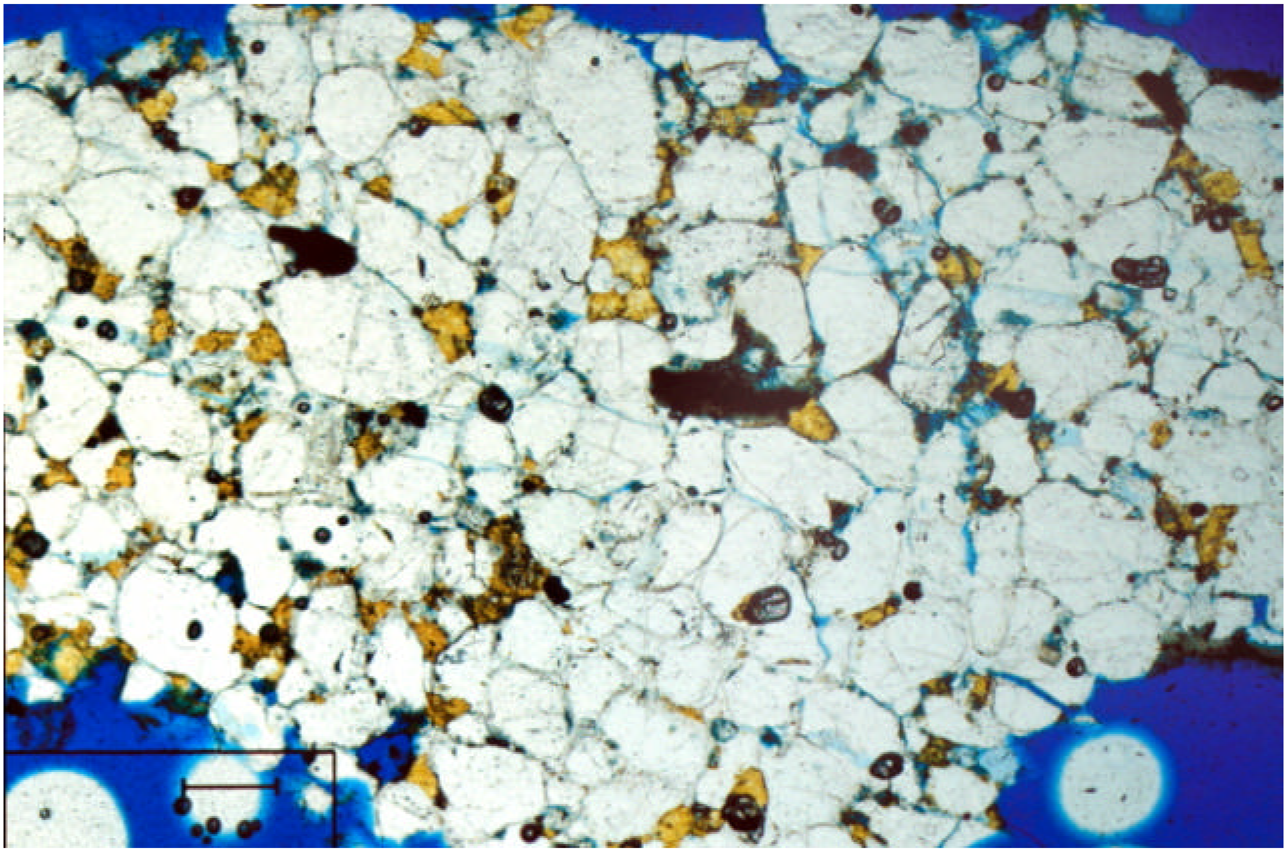

Figure 16c. Thin-section of Elmhurst sandstone drill cutting chip at Herscher Field. Fine to medium-grained sandstone with fine-grained k-feldspar (yellow stained) are moderately well-cemented by silica. Sample from the Natural Gas Storage Company of Illinois, Armstrong # M-1 (Sec 31, T30N, R10E, Kankakee County, IL), 2585'. Bar scale is 0.25mm long.

Figure 17a. Rounded, coarse, quartz grains from cuttings at the top of the Mt. Simon Sandstone at Herscher NW Field. Sooty grains typical of the Elmhurst are absent. The quartz grains are very rounded without significant quartz overgrowth facets and reflect a friable, porous, reservoir lithology. Field of view is approximately 6mm across. Sample from the Natural Gas Pipeline Co. of America, #1 L. Dunn (Sec. 3, T30N, R9E, Kankakee Co., IL), 2290'.

Figure 17b. Cuttings of the Mt. Simon Sandstone from Herscher NW Field. The left grain is a fine-grained, feldspathic (orange k-feldspar) sandstone. The center grain is a friable weakly quartz-cemented coarse-grained sandstone. The right grain is a medium-grained, very friable quartz sandstone. Sample from the Natural Gas Pipeline Co. of America, #1 L. Dunn (Sec. 3, T30N, R9E, Kankakee Co., IL), 2300'.

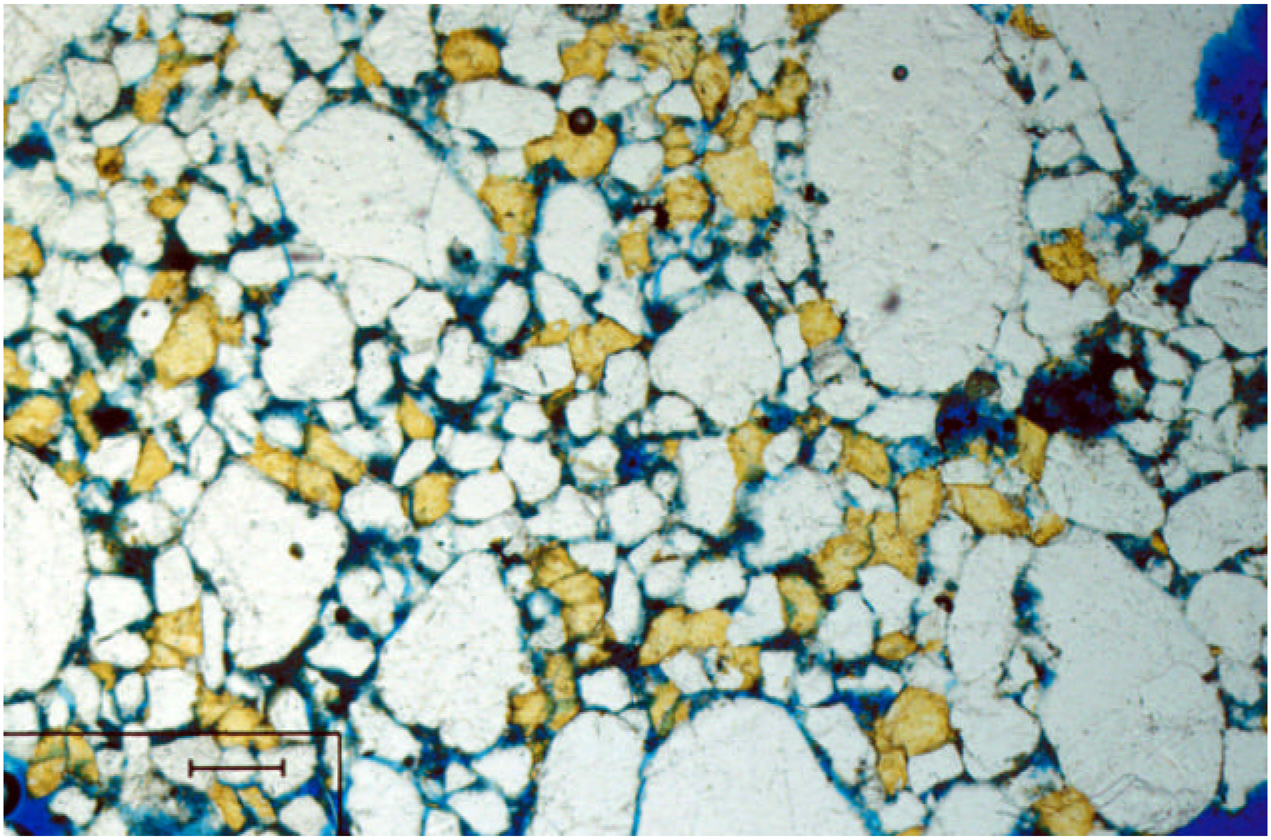

Figure 17c. Thin section of cuttings from the top of the Mt. Simon Sandstone. Coarse and fine-grained quartz and fine-grained k-feldspar (stained yellow) are weakly cemented, forming an excellent quality reservoir rock. Sample from the Natural Gas Storage Company of Illinois, Armstrong # M-1 (Sec 31, T30N, R10E, Kankakee County, IL), 2600’. Bar scale is 0.25mm long.

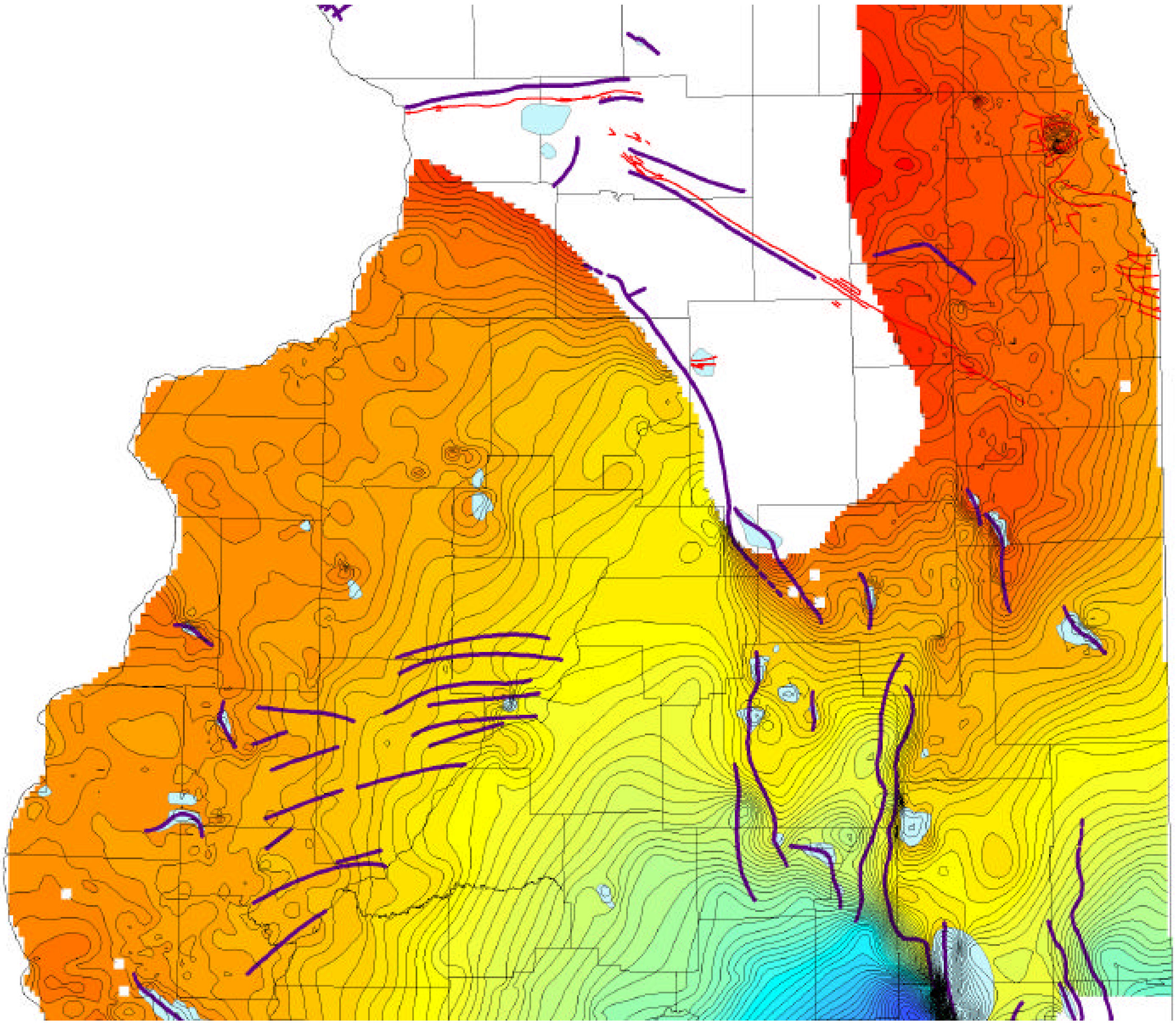

Figure 18. Generalized northern Illinois regional structure map of the top of the Ordovician Trenton Limestone. CI=100'. Orange colors are shallow and blue are deep. The light blue areas are anticlinal closures. The purple lines are major fold axes and the red lines are principal fault traces, as mapped by Nelson (1995). The white area in northern Illinois is where the Trenton has been eroded.