[PS]Potential for Petroleum Production in Mississippian-Pennsylvanian Paleovalleys in the Main Consolidated Field (Crawford County, Illinois) and Application throughout the Illinois Basin*

Jeremy London[1], Andrew Reeder[1], and Michael T. May[1]

Search and Discovery Article #10501 (2013)**
Posted July 22, 2013

*Adapted from poster presentation given at AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 19-22, 2013

[1]Department of Geography and Geology, Western Kentucky University (jeremy.london@topper.wku.edu)

Abstract

Paleovalleys associated with the Mississippian-Pennsylvanian uncomformity have been identified as unconventional targets for potential hydrocarbon exploration in the Illinois Basin. The extent to which the paleovalleys have been explored and exploited for hydrocarbons is largely undocumented.

The Main Consolidated Field in Crawford County, Illinois has produced hydrocarbons from a basal Pennsylvanian reservoir occurring in lenticular conglomeratic sand bodies. Major pay zones in this field include Pennsylvanian sandstones, such as the Robinson, and older Chesterian zones as well. Due to the discrete nature of the channel sands and the difficulty in identifying the Mississippian-Pennsylvanian unconformity, these paleovalley traps may go unnoticed.

Much work has been done to identify the Mississippian-Pennsylvanian disconformity, characterize the Chesterian and basal Pennsylvanian Caseyville lithology, and delineate the pre-Pennsylvanian paleovalleys in the Illinois Basin. This study explores the potential for hydrocarbon production from Mississippian-Pennsylvanian paleovalleys in the Main Consolidated Field in Crawford County, Illinois and its implications throughout the basin.

Potential for Petroleum Production in Mississippian-Pennsylvanian Paleovalleys in the Main Consolidated Field (Crawford County, Illinois) and Application throughout the Illinois Basin

Jeremy T. London, Andrew D. Reeder and Dr. Michael T. May
Western Kentucky University
Department of Geography and Geology, Illinois Basin Group

Abstract

Paleovalleys associated with the Mississippian-Pennsylvanian uncomformity have been identified as targets for potential hydrocarbon exploration in the Illinois Basin. The extent to which the paleovalleys have been explored and exploited for hydrocarbons is largely undocumented. Much work has been done to identify the Mississippian-Pennsylvanian disconformity, characterize the Chesterian and basal Pennsylvanian Caseyville lithology, map the sub-Pennsylvanian paleogeology and delineate the pre-Pennsylvanian paleovalleys in the Illinois Basin. This study uses GIS to integrate past mapping efforts and paleovalley studies to characterize petroleum production trends from pre-Pennsylvanian paleovalleys in the Illinois Basin and identify areas with potential hydrocarbon-bearing paleovalley fill.

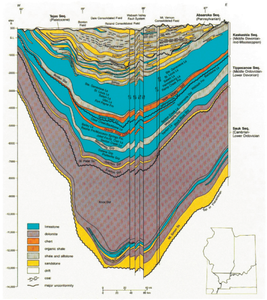
Kernel density estimation was used to approximate drilling activity throughout the basin and identify "hotspots" of high well density. Pennsylvanian oil and gas fields were used to parse out which hotspots are related to Pennsylvanian production. Those hotspots were then compared to structural features and subPennsylvanian paleogeology to determine the geologic conditions controlling hydrocarbon accumulation in paleovalleys and identify areas with the potential for hydrocarbon-bearing paleovalleys. Subsurface mapping was used to confirm the presence of a paleovalley trap in one of the potential areas.

The distribution of hydrocarbon-bearing paleovalleys in the structurally controlled upper two thirds of the Illinois Basin is controlled by the presence of hydrocarbon-charged Chesterian units incised by paleochannels. Migration of hydrocarbons into paleovalleys in the lower one third of the Illinois Basin is mostly fault-related, with production being isolated to the Wabash, Rough Creek and Pennyrile Fault Zones. The Main Consolidated Field in Crawford County, Illinois was chosen as the best site for subsurface mapping due to its high well density, associated Pennsylvanian production and locally incised productive Chesterian strata. Four cross sections revealed a complex paleovalley reservoir with multiple pay zones. The methodology used to locate this paleovalley reservoir can be applied to other potential sites within the Illinois Basin and to other basins as well.

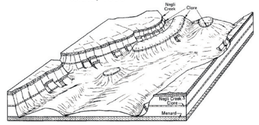
Introduction

The Illinois Basin is an intracratonic sedimentary basin that underlies southwestern Indiana,western Kentucky and most of Illinois. Sediments deposited during the Paleozoic have been major producers of oil and gas throughout the region. The Mississippian-Pennsylvanian unconformity was a period of erosion which occurred between the Kaskaskia depositional sequence (Middle Devonian – Upper Mississippian) and the Absaroka depositional sequence (Pennsylvanian – Lower Permian). The systemic boundary marks a period of erosion at the early Pennsylvanian, during which beds of the Chesterian age (Late Mississippian) were incised by streams to create an anastomosing network of paleovalleys.

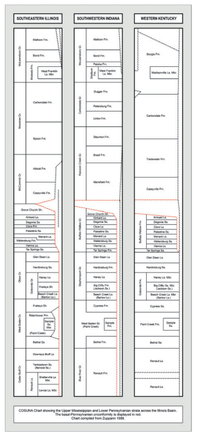
During the Late Mississippian (Chesterian), the seas regressed and siliciclastics derived from the Canadian Shield via the Michigan river system were deposited. At the end of the Mississippian, the Illinois Basin was exposed to subaerial erosion and was peneplained. Subsequent uplift of the peneplain caused deep paleovalleys (up to 450 feet) to incise the Upper Mississippian sediments in a southwesterly direction. During the Early Pennsylvanian, as the seas transgressed, paleovalleys were filled with sandstone, shale, siltstone, limestone and coals of the Caseyville,Tradewater and Mansfield strata. These sediments unconformably overlie Chesterian sediments of various ages throughout nearly the entire Illinois Basin.



-Kolata, 1990



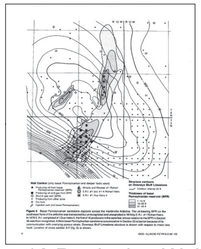
-Bristol and Howard, 1974

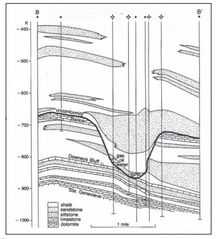


Previous Studies

There is limited documentation of hydrocarbon production in paleovalleys in the Mississippian-Pennsylvanian unconformity in the Illinois Basin. One of the only documented examples occurs in the Main Consolidated Field in Crawford County, Illinois along the Benton-Fairfield paleovalley. The basal Pennsylvanian reservoir consists of a lenticular sand body which incises the Hardinville Anticline -- a northwest-southeast oriented structural feature at the southern termination of the La Salle Anticlinal Belt. The paleovalley incises the anticline's hingle line at a perpendicular angle, indicating that the deformation occurred during or after incisement.

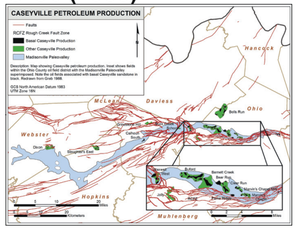
Howard and Whitaker (1988, 1990)



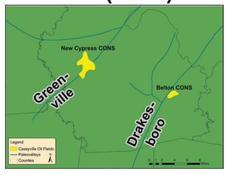


- 16 Producing Wells
- 1.4 MMBO (estimated recoverable oil)

Shiarella (1933)
Greb (1988)

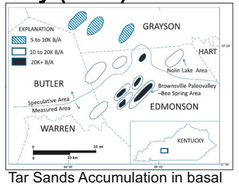


Rose (1963)



Caseyville Producing Oil Fields
Muhlenberg County, Kentucky

Noger (1984)
May (2013)



Tar Sands Accumulation in basal Pennsylvanian Caseyville of the Brownsville Paleovalley
Edmonson County, Kentucky

Data

Data used in this research is from secondary sources. Well records were obtained from the Kentucky, Indiana and Illinois Geological Surveys and include attributes such as well id, current operator, status (oil, gas, water, dry), initial production rates (in bopd or Mcfpd) , date of completion, date of plugging, target reservoir, status (active or inactive), elevation, total depth, latitude and longitude, perforations intervals and other data. Public Land Survey System/Carter grids, faults, and structural features were obtained from the geological surveys as well. Well logs were procured exclusively from the Illinois State Geological Society using the Illinois Oil and Gas Resources Internet Map Service. Illinois Basin-wide sub-Pennsylvanian paleogeology and paleovalley maps were pulled from Bristol and Howard (1971). An isopach of the basal Pennsylvanian reservoir documented in Crawford County, Illinois was pulled from Howard and Whitaker (1988). State and county boundaries were obtained from the U.S. Census Bureau. The Illinois Basin boundary was georeferenced and digitized by Andrew Reeder from Buschbach and Kolata (1990).

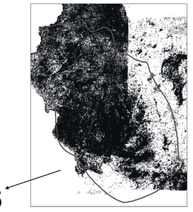
Data Processing/Manipulation

Basinwide data was integrated into GIS for regional characterization of production trends from Miss-Penn paleovalleys. Much of the data needed for regional characterization was not in a georeferenced format. Bristol and Howard's (1971) paleovalley and sub-Pennsylvanian paleogeology maps had to first be georeferenced and digitized. The maps were imported and georeferenced using the georeference toolbar in ArcGIS. The township and range grid in Illinois and Indiana and the Carter coordinate system in Kentucky were used as references for choosing control points. Attributes, such as name and type (trunk or tributary), were entered as the features were digitized.

Data

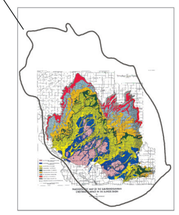
Structure/Faults

Wells



GIS

Paleovalleys

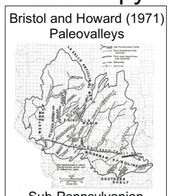


Sub-Pennsylvanian Paleogeology

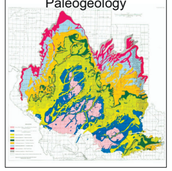
Georeference/Digitization

Hard Copy

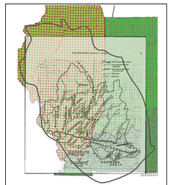
Bristol and Howard (1971) Paleovalleys

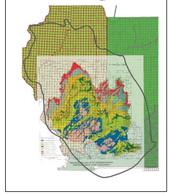


Sub-Pennsylvanian Paleogeology

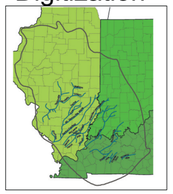


Georeference

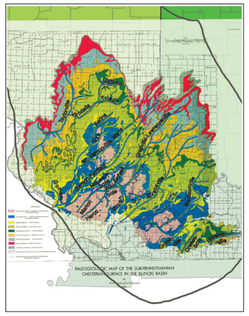




Digitization



Final Product



Sedimentation Seminar (1978) "Much of the oil from formations of Pennsylvanian age in the Illinois Basin comes from basal Pennsylvanian Caseyville...Sandstones that occur as fill in paleovalleys."

Howard and Whitaker (1988) "Those traps associated with paleovalleys at the Mississippian - Pennsylvanian unconformity could prove to be important targets for future oil and gas exploration."

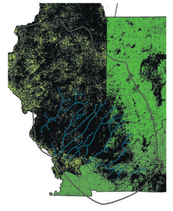
ISGS, IGS and KGS (1988) "Conglomeratic sandstones deposited within these [paleo] valleys were commonly buried by transgressive Pennsylvanian marine shales, thus creating the potential for stratigraphic entrapment of hydrocarbons."

Oltz et al. (1990) "Paleovalley fill at the sub-Absaroka unconformity was a previously unrecognized or underexplored play within the [Illinois] basin."

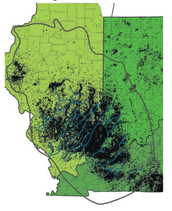
Kvale and Archer (2007) "The only documented example of basal Pennsylvanian production in an incised-paleovalley fill comes from the Main Consolidated field in eastern Illinois."

Well Data Manipulation

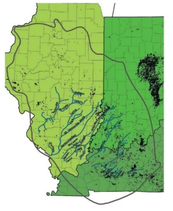
All Wells



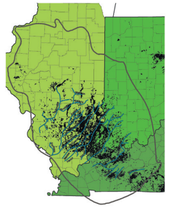
Dry Wells



Gas Wells



Oil Wells



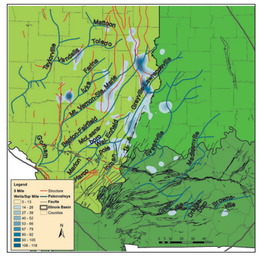
Kernel Density Estimation

Kernel density estimation was used to calculate wells per square mile for different well types (oil, gas, dry). The areas with the highest densities were highlighted for each type of well towards the creation of a density hotspot map. Many parameters were experimented with in order to find the appropriate set.

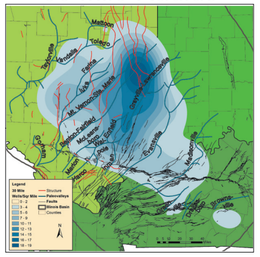
Since all wells, regardless of type, could be used for mapping later on, the kernel density of all wells reveals areas which have densest well distribution. Well control is critical for subsurface mapping due to the discrete nature of the paleovalley reservoirs. Areas were chosen along paleovalleys with high drilling density. These areas tend to occur where the paleovalleys intersect faults and structural features.

The 5 mile search radius produces a more local kernel density whereas the 30 mile search radius represents a more global model. For the purpose of this research, the 5 mile search radius was chosen. Also, the densities estimated using the 5 mile search radius are closer to the actual values of drilling density.

5 Mile Radius



30 Mile Radius



Local

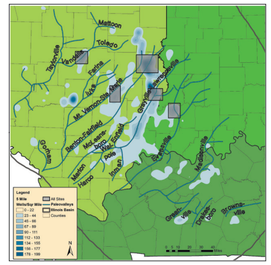
Global

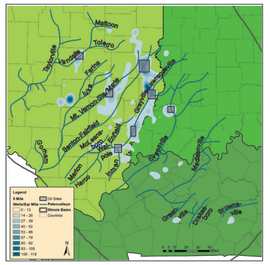
Site Selection

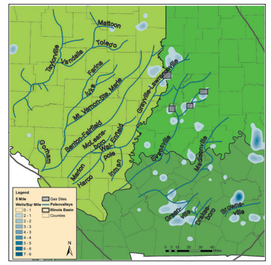
Since all wells, regardless of type, could be used for mapping later on, the kernel density of all wells reveals areas which have densest well distribution. Well control is critical for subsurface mapping due to the discrete nature of the paleovalley reservoirs. Areas were chosen along paleovalleys with high drilling density.

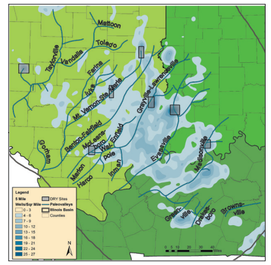
Oil wells are usually drilled next to other oil wells. This should mean that areas of high oil well density should also be areas of high oil production. The highest densities are in Illinois, towards the deeper part of the basin. There's a clear trend in oil well density running along the Grayville-Lawrenceville paleovalley. High oil well densities occur often where paleovalleys intersect faults and structural features.

There are far less gas wells than any other type of wells being analyzed. The major hotspots of gas occur on the flanks of the basin where the sediments are much shallower. There doesn't appear to be much gas associated with the paleovalleys, save some hotspots in Indiana and Kentucky. Many of the same oil and gas hotspots will have high dry well densities because people tend to drill wherever there have been previous discoveries. A dry well hotspot in the absence of high oil and gas well densities indicates an area of high failure rate.

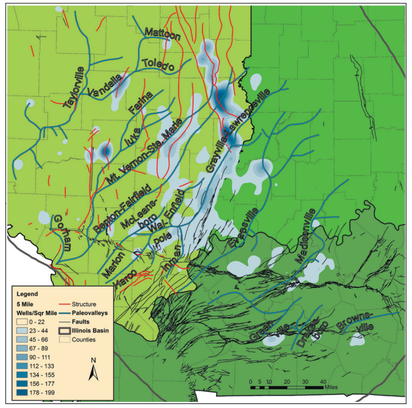




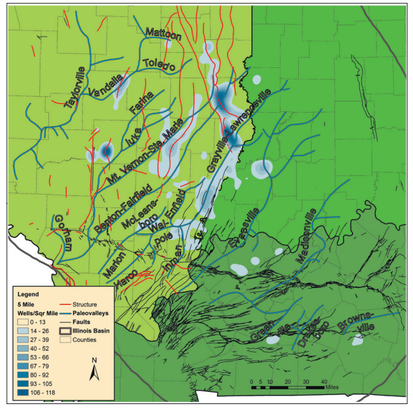




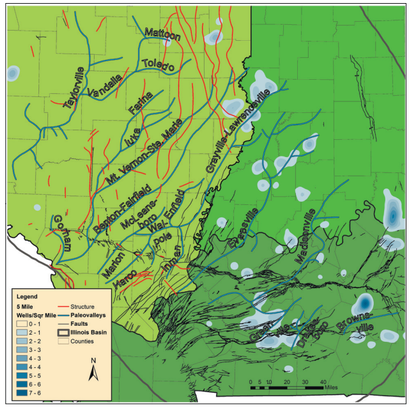
All Wells



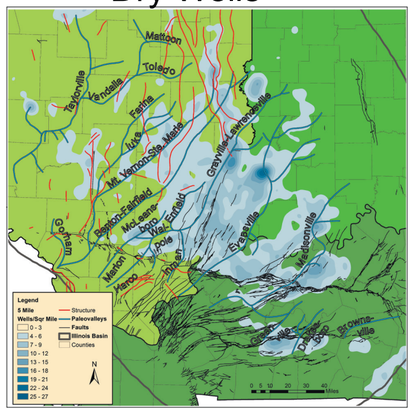
Oil Wells



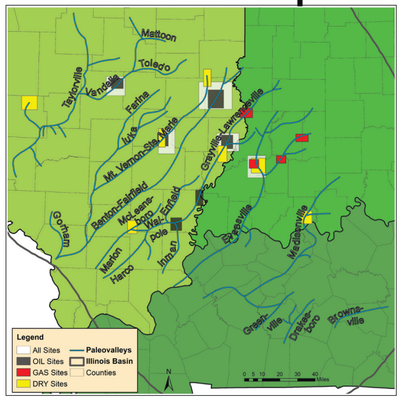
Gas Wells

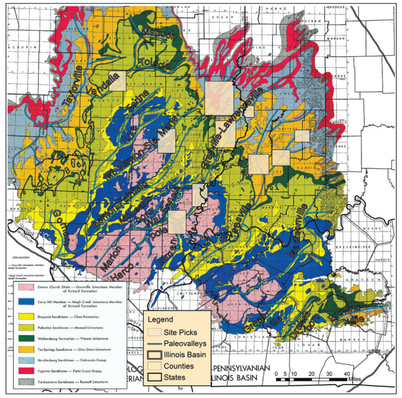


Dry Wells

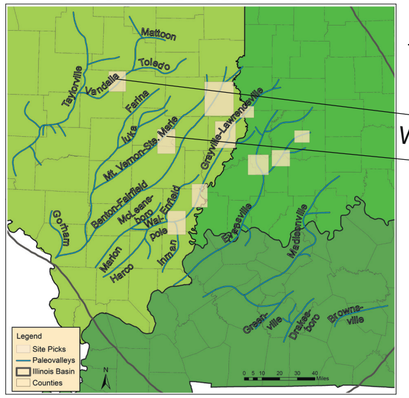


Attribute Map



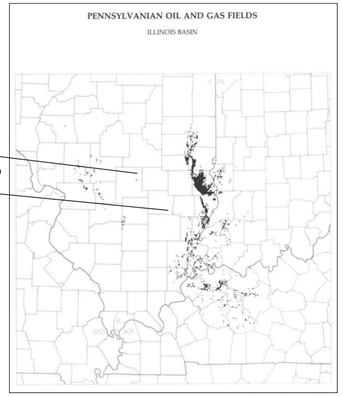


Initial Site Picks



Compare with known Pennsylvanian production

Why No Penn Production Here?

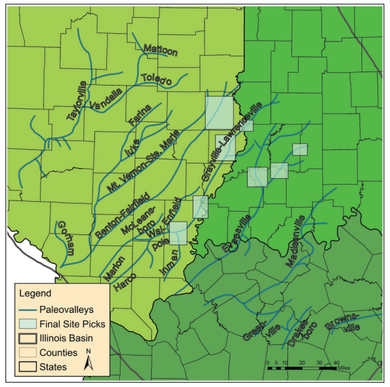


Explanation

The paleogeology indicates which Chesterian units lie directly below the Mississippian-Pennsylvanian unconformity. The paleovalleys incise Chesterian strata which is locally older than surrounding interfluvial areas, therefore linear bodies of locally older Chesterian strata can be inferred as paleochannels. Howard and Whitaker's (1988) paleovalley reservoir occurs as a bar deposit southeast of the Benton-Fairfield thalweg, which is shown on the map in blue. The reservoir occurs in locally older Cypress Sandstone/Paint Creek Group couplet.

The Cypress Sandstone is a known producer of oil and gas in this area. This area is also a hotspot for Pennsylvanian production, having the largest producing Pennsylvanian field in the Illinois Basin. The hotspots along the Mt. Vernon-Ste. Marie and Vandalia paleovalleys which do not correspond to Pennsylvanian oil and gas fields are located deeper in the basin. Here, the paleovalleys incise younger Chesterian strata of the Tar Springs-Golconda, Palestine-Menard and Degonia-Clore couplets. These sandstones are neither laterally extensive nor very productive in this part of the basin (Illinois and Indiana-Kentucky Geological Societies, 1988).

Final Site Picks



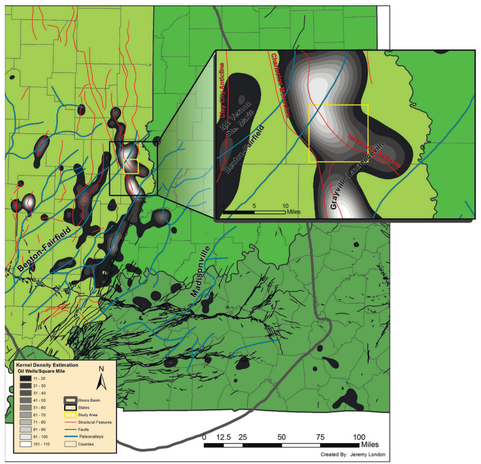
Discussion

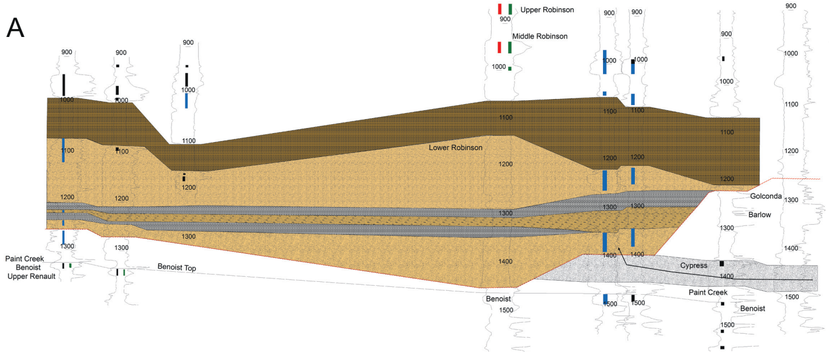
The regional study revealed the geologic conditions controlling the distribution of hydrocarbon accumulation in paleovalleys. Regarding hydrocarbon accumulation in paleovalleys, there is a correlation between oil-bearing sub-Pennsylvanian paleogeology and Pennsylvanian production. This explains why there's no significant Pennsylvanian production in the deeper part of the basin where the youngest Chesterian strata lie directly below the unconformity. In the upper two thirds of the Illinois Basin, migration of hydrocarbons into paleovalleys appears mostly controlled by the presence of hydrocarbons in underlying, incised Chesterian sediments. Pennsylvanian production in the lower third of the basin is most likely due to migration of hydrocarbons upward along the Rough Creek,Wabash Valley and Pennyrile Fault Zones. The southernmost selected sites along the Grayville-Lawrenceville paleovalley are probably related to the Wabash Valley Fault Zone.

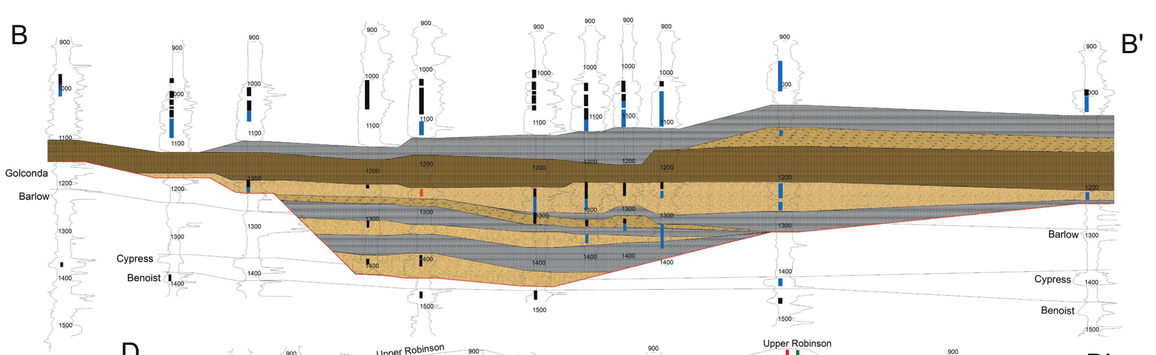
The sites along the Mt. Vernon-Ste. Marie and Vandalia paleovalleys were excluded due to their lack of documented Pennsylvanian oil and gas fields. The areas chosen have dense well spacing, which is necessary due to the discrete and transient nature of paleovalleys and the difficulty locating the unconformity in the subsurface. Sites had to have documented Pennsylvanian production to isolate density hotspots related to Pennsylvanian reservoirs as opposed to Mississippian and older strata. No sites were chosen in Kentucky, despite reported Pennsylvanian production along the Rough Creek and Pennyrile Fault Zones. The well densities here are much lower compared to other parts of the basin and the Pennsylvanian oil and gas fields are much less significant. Finally, the added complexity of the Rough Creek and Pennyrile Fault Zones would make the already arduous task of mapping the unconformity in the subsurface nearly impossible without accompanying seismic data. For these reasons, sites in Kentucky were not considered.

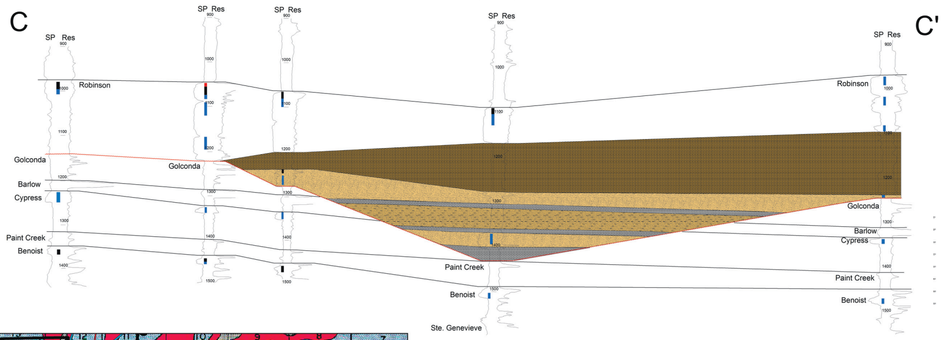
Subsurface Mapping

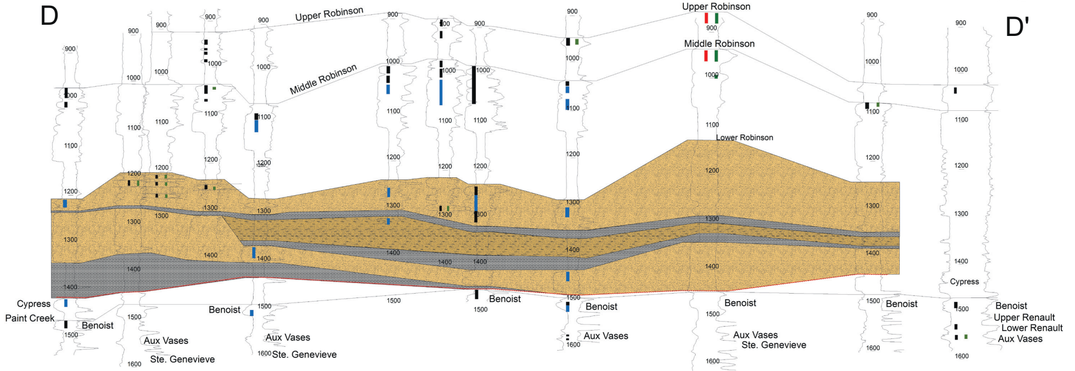
Of all the potential sites, Crawford County, Illinois is the most significant for paleovalley reservoir production. It contains the largest Pennsylvanian oil field in the Illinois Basin (Main Consolidated Field), has one of the highest oil well densities in the Illinois Basin, incises productive Chesterian sediments and has previously documented production from the basal Pennsylvanian reservoir. For these reasons, this site was selected for subsurface mapping.

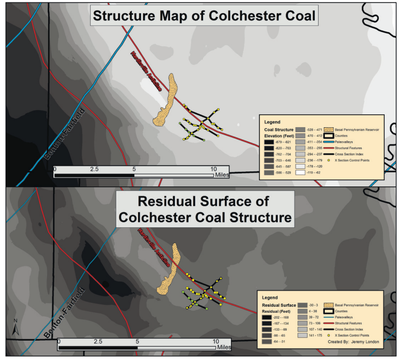


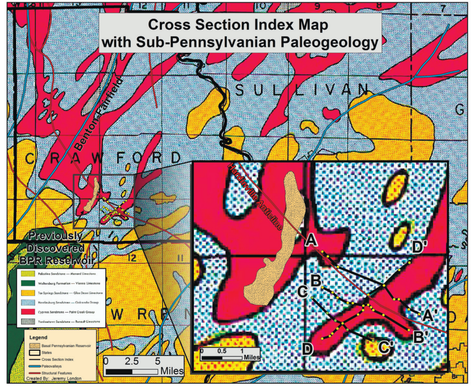












Discussion/Conclusion

This site is located at the southern termination of the La Salle Anticlinal Belt, which is one of the most prominent structural features in the Illinois Basin. Crawford County lies in a transitional zone between a shelf area to the east in Indiana and the steeply dipping basinward slope to the west. Caseyville and Tradewater sediments are indistinguishable in this area. Several informal names have been used to describe the undifferentiated basal Penn oil-bearing sandstones, but the Robinson is the most prolific (Illinois and Indiana-Kentucky Geological Societies, 1988). These Pennsylvanian sandstones can have thicknesses of up to 200 feet, but are not laterally persistent.

The youngest Chesterian strata range from the Cypress-Paint Creek to Tar Springs-Glen Dean couplets, but paleovalleys locally incise much older Chesterian sediments. Howard and Whitaker's (1988) elongate sandstone lens is located southeast of the main trunk of the Benton Fairfield paleovalley. The paleovalley trap trends northeast-southwest, incising perpendicularly the Hardinville anticline which has a northwest-southeast orientation.

The cross sections of the subsurface reveal a complex reservoir. Oil and gas found in the Pennsylvanian sandstones probably migrated from hydrocarbon-rich locally incised Chesterian strata, such as the Cypress and Benoist. Alternating layers of sandstone and shale were formed in a fluvial-estuarine environment, creating multiple stacked reservoirs, with shales acting as caprock.

The methodology used to locate the channel deposits was successful. A linear sand body was discovered on the first try. Further mapping of channel sands in the Main Consolidated Field could explain the complex deposition of these sediments and refine the paleovalley play model. Untapped reservoirs might also be discovered in the process. This methodology can also be applied to other areas in the basin.

The character of the paleovalley fill changes rapidly over relatively short distances. Give the discrete nature of the linear sand bodies, a very close well spacing is needed to identify them with well logs. Kernel density estimation of oil wells revealed Crawford County to have one of the highest density of oil wells in the Illinois Basin. This makes Crawford County a prime candidate for future mapping of the Mississippian-Pennsylvanian unconformity and associated paleovalley fill.

References

Bristol, H. M and Howard, R.H. (1971). Paleogeologic Map of the Sub-Pennsylvanian Chesterian (Upper Mississippian) Surface in the Illinois Basin. *Illinois State Geological Survey*, Circular 458.

Greb, S. F. (1988). Hydrocarbon Production from the Sub-Pennsylvanian Paleovalleys of Western Kentucky: *Kentucky Geological Survey: Open-File Report OF-88-15.*

Howard, R. H. and Whitaker, S. T. (1988). Hydrocarbon accumulation in a paleovalley at Mississippian-Pennsylvanian unconformity near Hardinville, Crawford County, Illinois: a model paleogeomorphic trap. *Illinois Petroleum 129.* 26 p.

Howard, R. H., and Whitaker, S. T. (1990). Fluvial-estuarine valley fill at the Mississippian-Pennsylvanian unconformity, Main Consolidated Field, Illinois, in J.H Barwis, J.G. McPherson and J.R.J. Studlick, Sandstone Petroleum Reservoirs, casebooks in earth science: New York, Springer-Verlag, p. 319-341

Illinois and Indiana-Kentucky Geological Societies. (1988). Geology and Petroleum Production of the Illinois Basin, Volume 2. *Illinois and Indiana-Kentucky Geological Societies.* Indiana Geological Survey, Bloomington IN.

Kvale, E. P. and Archer, A. W. (2007). Paleovalley fills: Trunk vs. Tributary. *American Association of Petroleum Geologists Bulletin,* vol. 91, no.6. pp. 809-821

May, M. T. (2013). Oil-saturated Mississippian-Pennsylvanian sandstones of south-central Kentucky, in F.J. Hein, D. Leckie, S. Larter, and J. R. Suter, eds., Heavy-oil and oil-sand petroleum systems in Alberta and beyond: AAPG Studies in Geology 64, p. 373-405.

Noger, M.C. (1984). Tar-sand resources of western Kentucky. 1984 Eastern Shale Symposium, Kentucky Institute for Mining and Minerals Research, Kentucky Energy Cabinet.

Oltz, D. F.; Rupp, J. A.; Keith, B.; Beard, J. 1990. Future Hydrocarbon Opportunities in the Illinois Basin. *Interior Cratonic Basins.* Illinois Geological Survey.

Rose, W.D. (1963). Oil and gas of Muhlenburg County, Kentucky. Kentucky Geological Society, Series X, Bulletin 1.

Sedimentation Seminar. (1978). Sedimentology of the Kyrock Sandstone (Pennsylvanian) in the Brownsville Paleovalley, Edmonson and Hart Counties, Kentucky: Kentucky Geological Survey Report of Investigations 21, 24 p.

Acknowledgements

USGS science for a changing world

ISGS Illinois State Geological Survey

Kentucky Geological Survey
UNIVERSITY OF KENTUCKY

ESRI

WKU