STRATIGRAPHY OF THE CAMBO-ORDOVICIAN SUCCESSION IN ILLINOIS

TOPICAL REPORT

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An Evaluation of the Carbon Sequestration Potential of the Cambro-Ordovician Strata of the Illinois and Michigan Basins

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DISCLAIMER:

ABSTRACT
The Upper Cambrian through Lower Ordovician succession (Sauk II-III sequences) in the Illinois Basin covers the entire state of Illinois and most of the states of Indiana and Kentucky. To determine lateral and vertical lithologic variations of the rocks within the Cambro-Ordovician deposits that could serve as reservoir or seal for CO_2 storage, detailed subsurface stratigraphic evaluation of the succession in Illinois was conducted. The Cambro-Ordovician succession in the Illinois Basin consists of mixed carbonate-siliciclastic deposits. Its thickness ranges from nearly 800 feet in the extreme northwest to nearly 8000 feet in the Reelfoot Rift in the extreme southeastern part of the state.

In northern and central Illinois, the Cambro-Ordovician rocks are classified as the Cambrian Knox and the Ordovician Prairie du Chien Groups, which consist of alternating dolomite and siliciclastic units. In the southern and deeper part of the Illinois Basin, the Cambro-Ordovician deposits consist chiefly of fine to coarsely crystalline dolomite capped by the Middle Ordovician Everton Formation. Detailed facies analysis indicates that the carbonate units consist mainly of mudstone to grainstone facies (fossiliferous/oolitic limestone and dolomite) with relics of bioclasts, ooids, intraclasts and peloids recording deposition on a shallow marine ramp setting.

The dominant lithology of the Knox and the overlying Prairie du Chien Group is fine to coarsely crystalline, dense dolomite. However, porous and permeable vugular or fractured/cavernous dolomite intervals that grade to dense fine to coarsely crystalline dolomite are present within the dolomite units. Several hundred barrels of fluid were lost in some of these porous intervals during drilling, indicating high permeability. The sandstone intervals are porous and permeable and are texturally and compositionally mature. The permeable sandstone and porous dolomite intervals are laterally extensive and could serve as important reservoirs to store natural gas, CO_2 or hazardous waste material. Results of this study show that the Cambro-Ordovician Knox Group in the Illinois Basin and adjacent Midwestern regions may be an attractive target for CO_2 sequestration because these rocks are 1) laterally extensive, 2) consist of some porous and permeable dolomite and sandstone intervals, and 3) contain abundant impermeable shale and carbonate seals.

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EXECUTIVE SUMMARY

The objective of this study was to determine lateral and vertical lithologic variations of the rocks within the Upper Cambrian through Lower Ordovician succession (Sauk II-III sequences) deposits in Illinois that could serve as reservoir or seal for CO2 storage. More than 1000 deep wells penetrating the Mt. Simon Sandstone were studied for detailed subsurface stratigraphic evaluation of the Knox succession. The Cambro-Ordovician rocks in the Illinois Basin consists of mixed carbonate-siliciclastic deposits. It thickens in a southeast direction; its thickness ranges from nearly 800 feet in the extreme northwest to nearly 8000 feet in the Reelfoot Rift in the extreme southeastern part of the state. The succession overlies, with a gradational contact, the Middle Cambrian Mt. Simon Sandstone and underlies, with the major sub-Tippecanoe unconformity, the Upper Ordovician St. Peter Sandstone.

In northern and central Illinois, the Cambro-Ordovician rocks are classified as the Cambrian Knox and the Ordovician Prairie du Chien Groups, which consist of alternating dolomite and siliciclastic units. The Upper Cambrian Knox Group includes, from base to top, the Eau Claire Formation, Galesville and Ironton Sandstones, Franconia Formation, Potosi Dolomite, and the Eminence Formation that grades laterally into the Jordan Sandstone in the extreme northwest part of the state. The Lower Ordovician Prairie du Chien Group comprises the Gunter Sandstone at the base followed by Oneota Dolomite, New Richmond Sandstone, and the Shakopee Dolomite. The siliciclastic intervals thin southward and in the southern and deeper part of the Illinois Basin, the contacts of the dominantly carbonate units cannot be determined with confidence. Long regarded as the undifferentiated Knox Group, the Cambro-Ordovician succession in southern Illinois consists chiefly of fine to coarsely crystalline dolomite capped by the Middle Ordovician Everton Formation.

Detailed facies analysis indicates that the carbonate units consist mainly of mudstone to grainstone facies (fossiliferous/oolitic limestone and dolomite) with relics of bioclasts, ooids, intraclasts and peloids recording deposition on a shallow marine ramp setting. Porous and permeable vugular or fractured/cavernous dolomite intervals that grade to dense fine to coarsely crystalline dolomite are present within the dolomite units. Several hundred barrels of fluid were lost in some of these porous intervals during drilling, indicating high permeability. The sandstone intervals are porous and permeable and are texturally and compositionally mature.
The permeable sandstone and dolomite intervals are laterally extensive and could serve as important reservoirs to store natural gas, CO2 or hazardous waste material. The dominant lithology of the Knox and the overlying Prairie du Chien Group is fine to coarsely crystalline, dense dolomite. The intercrystalline pore space of the dolomite was lost as a consequence of late stage diagenetic dolomite overgrowth or cementation. The dense dolomite intervals, therefore, could serve as an effective seal for the encompassing porous and permeable sandstone and dolomite intervals.

The results of this study show that the Cambro-Ordovician Knox Group in the Illinois Basin may be an attractive target for CO2 sequestration because these rocks are 1)

laterally extensive, 2) consist of some porous and permeable dolomite and sandstone intervals, and 3) contain abundant impermeable shale and carbonate seals. This topical report is part of a larger project, United States Department of Energy under cooperative agreement DE-FE0002068 from 12/08/2009 through 9/31/2013.

OBJECTIVES

This research evaluated lateral and vertical lithologic and facies variations of the rocks within the Cambro-Ordovician deposits that could serve as reservoir or seal for CO2 storage using the available data. More than 1000 deep wells penetrating the Mt. Simon Sandstone were studied in detail. Over 70 wells were selected for detailed examination of well cuttings, available cores, and geophysical logs for stratigraphic analyses and regional correlation of the Cambro-Ordovician rock units. Nearly 60,000 feet of rocks (over 8,000 well samples and core chips, and 470 thin sections) from 30 deep wells were examined for this study. In addition, samples from exposures in west-central Missouri and a core from an exploratory well in northern St. Louis County, Missouri were studied and the results were compared with rocks encountered in the Illinois subsurface.

The project tasks comprised lithofacies, facies and stratigraphic analyses of several lithostratigraphic units including, from base to top, the Cambrian Eau Claire Formation, Galesville and Ironton Sandstones, Franconia Formation, Potosi Dolomite, Eminence Formation, and the Lower Ordovician Gunter Sandstone, Oneota Dolomite, New Richmond Sandstone, and the Shakopee Dolomite.

INTRODUCTION AND BACKGROUND

Sedimentary basin stratigraphy determines factors that are favorable for CO2 sequestration that is an important strategy for continued utilization of fossil fuel to meet the world's energy demand. Thickness, lateral extent, porosity and permeability, and the depth of stratigraphic intervals, as well as, the presence of thick effective impermeable seals are among the factors that control the feasibility of CO2 sequestration in deep saline formations. The northwest-southeast thickening Cambro-Ordovician succession in the Illinois Basin (Fig. 1) covers the entire state of Illinois and most of the states of Indiana and Kentucky. It is a part of the Great American Bank that existed on the Laurentian continent during Cambrian, Early Ordovician, and earliest Middle Ordovician (Fritz et al. (2012). The succession in Illinois consists of carbonate and siliciclastic units and its thickness ranges from nearly 800 feet in the extreme northwest to over 7300 feet in the Reelfoot Rift in the extreme southeastern part of the state (Fig. 2). It constitutes the main part of the Middle Cambrian through Lower Ordovician Sauk II-III subsequences of Palmer (1981) and Palmer et al. (2012).

The Knox succession overlies, with a gradational contact, the Middle Cambrian Mt. Simon Sandstone and underlies, with the major sub-Tippecanoe unconformity, the Upper Ordovician St. Peter Sandstone. In northern and central Illinois, the Cambro-Ordovician rocks are classified as the Cambrian Knox and the Ordovician Prairie du Chien Groups

(Buschbach, 1975; Willman and Buschbach, 1975), which consist of alternating dolomite and siliciclastic units. In the southern and deeper part of the Illinois Basin, the siliciclastic intervals are absent and the Cambrian through Lower Ordovician succession has long been

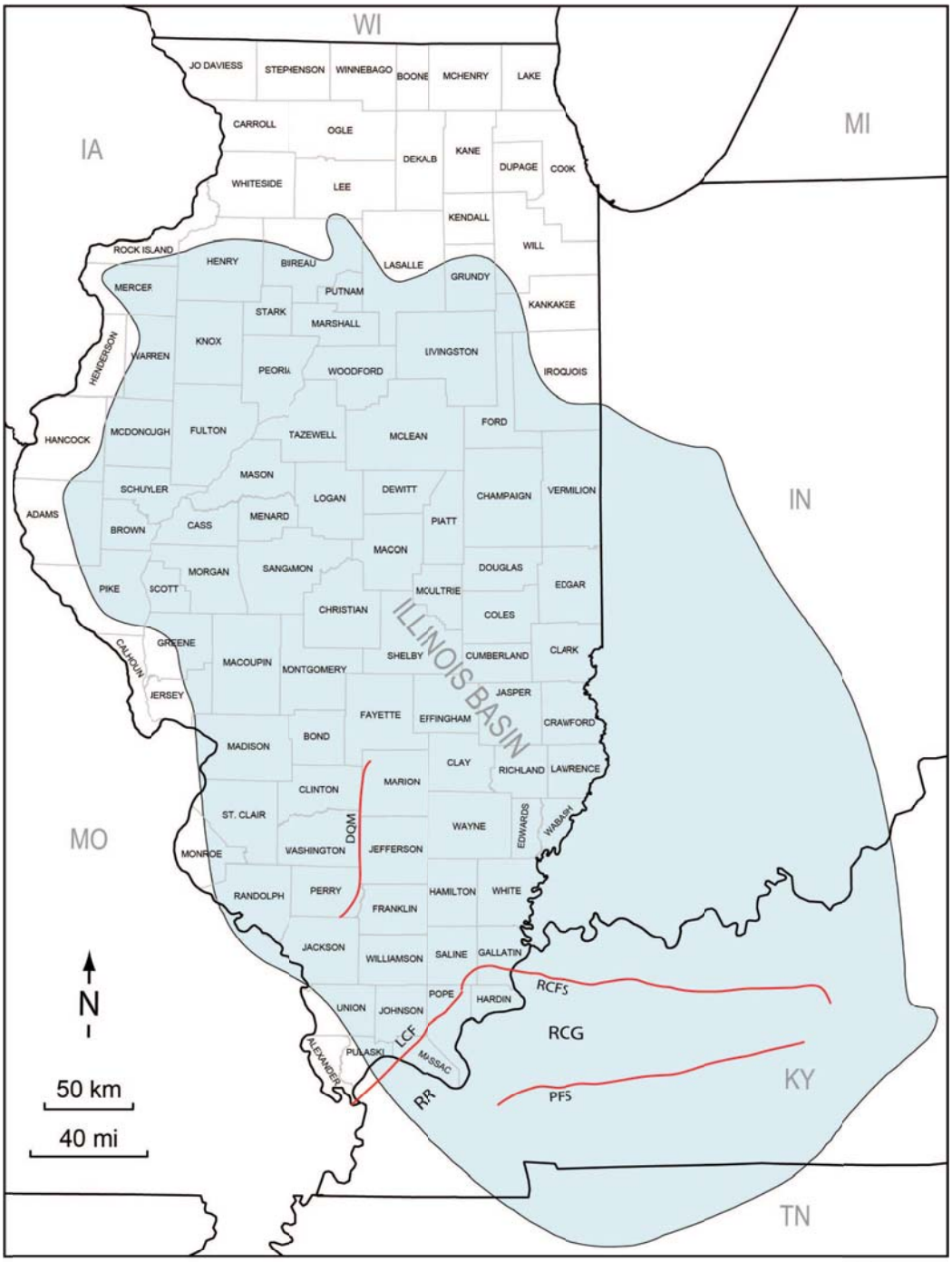


Figure 1: location of the Illinois Basin in light blue (Buschbach and Kolata, 1991); LCF: Lusk Creek Fault; PFS: Pineville Fault System; RR: Reelfoot Rift; RCG: Rough Creek Graben; RCFS: Rough Creek Fault System (Fault trace after Kolata and Nelson, 1991).

regarded as the undifferentiated Knox Group.

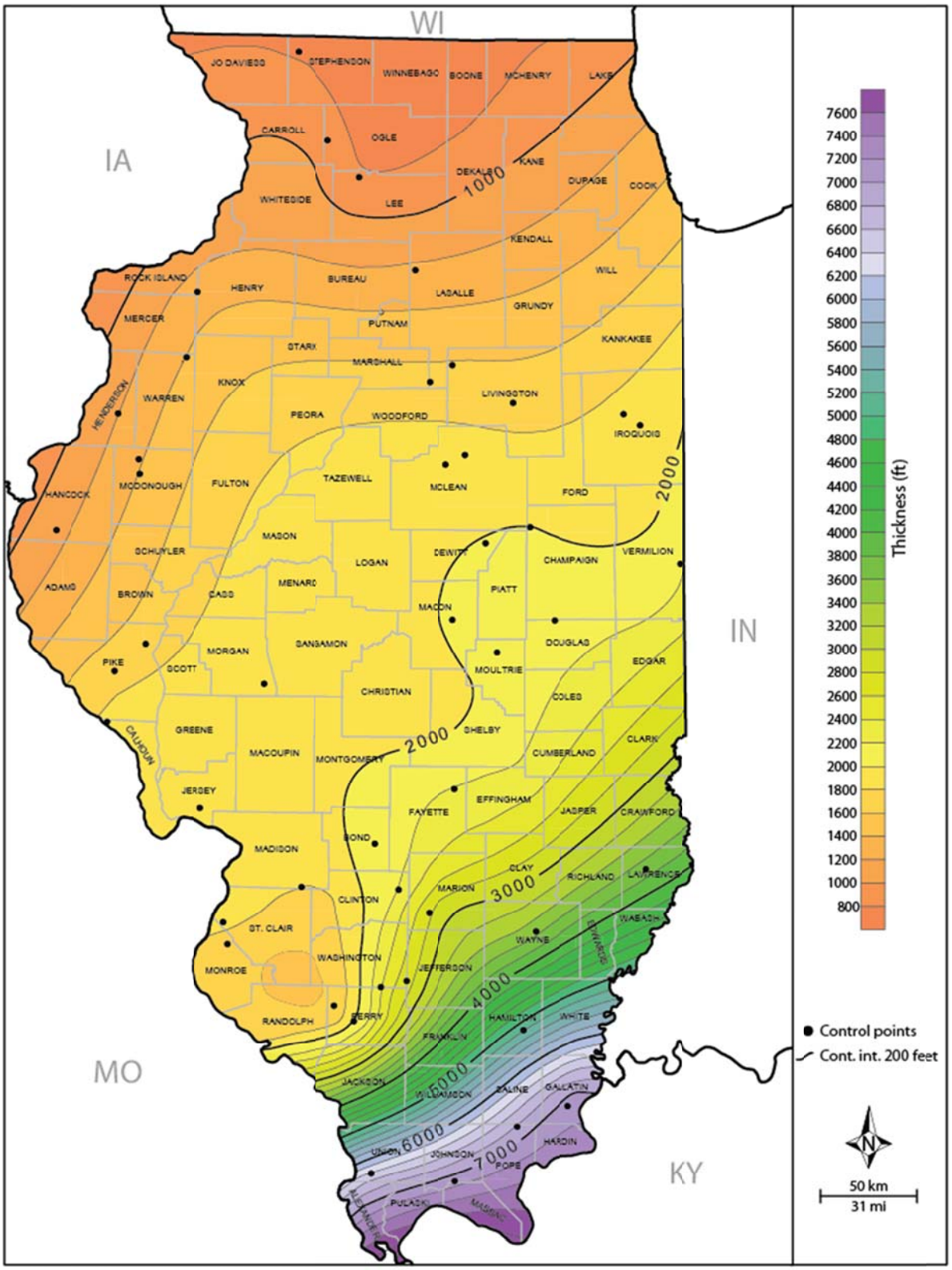


Figure 2: Isopach map of the Cambro-Ordovician Knox. deposits.

GEOLOGIC AND STRATIGRAPHIC SETTING

The intracratonic Illinois Basin (Figs. 1 and 3) is surrounded by a series of prominent structural features and was formed on the Precambrian crust of North America, in the Laurentian continent, during the Cambrian (Kolata and Nelson, 1991). The basin began subsiding in the Middle to Late Cambrian over the northeast extension of the Late Precambrian to Middle Cambrian Reelfoot Rift system (Kolata and Nelson, 1991, 2011). The rift system was associated with the Late Precambrian to Early Cambrian breakup of the Rodinia supercontinent (e.g., Bond et al., 1984; Piper, 2004).

The Cambrian and the Lower through lowermost Middle Ordovician rocks of the Illinois Basin that overlies the Mt. Simon Sandstone is classified as the Knox Dolomite Megagroup (Buschbach, 1975). The Knox constitutes the main part of the Sauk and the lowermost part of the Tippecanoe Sequence (Sloss, 1963). The Knox succession underlies, with the major sub-Tippecanoe unconformity, the Upper Ordovician St. Peter Sandstone and conformably overlies the Middle Cambrian Mt. Simon Sandstone.

In northern and central Illinois, the Cambro-Ordovician rocks are classified as the Cambrian Knox and the Ordovician Prairie du Chien Groups (Buschbach, 1975; Willman and Buschbach, 1975; Kolata, 2011), which consist of alternating dolomite and siliciclastic

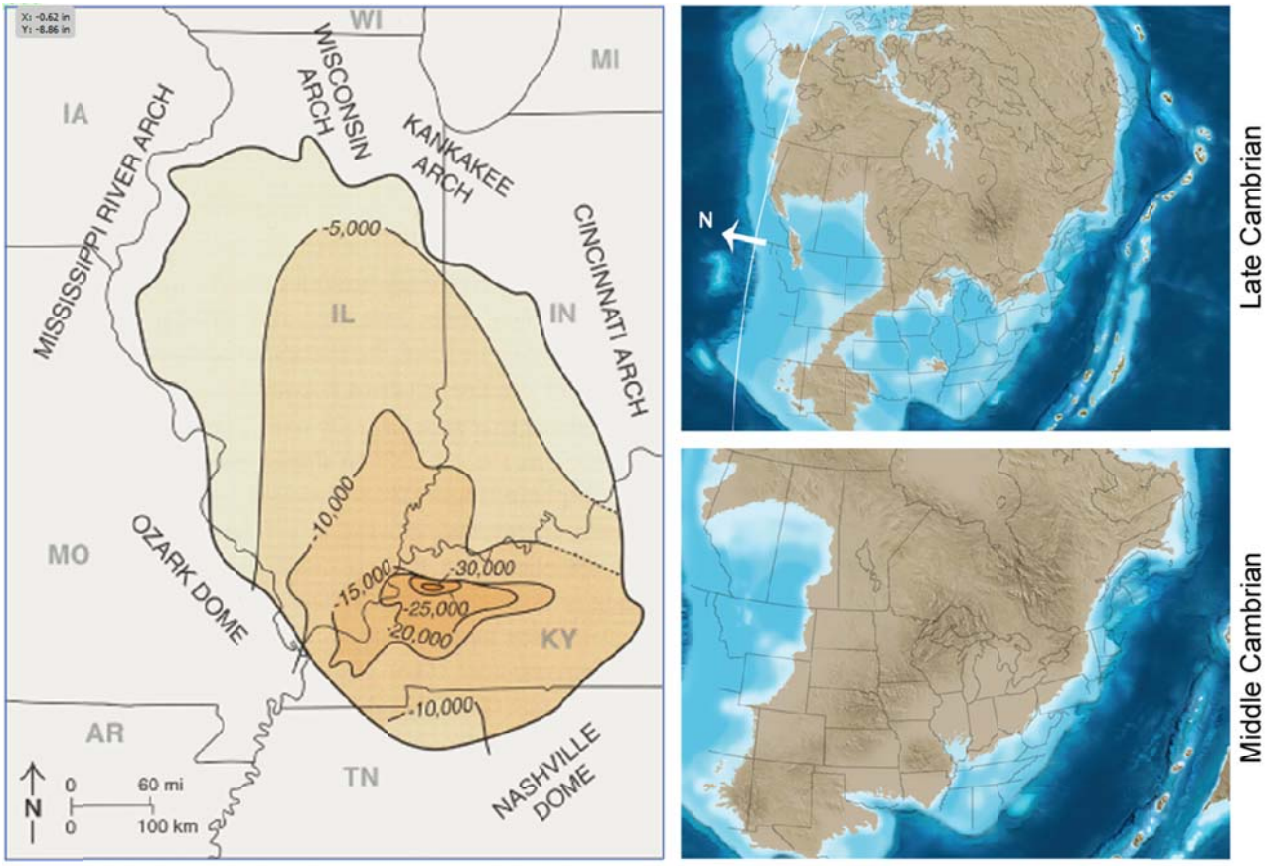


Figure 3: Illinois Basin surrounded by prominent arches and domes (Kolata and Nelson, 2011) and the Cambrian Paleogeography of the Laurentia (rblakey@cpgeosystems.com).

units (Figs. 4 through 6). The Cambrian Knox Group in Illinois includes, from base to top, the Eau Claire Formation, Galesville and Ironton Sandstones, Franconia Formation, Potosi Dolomite, and the Eminence Formation that grades laterally into the Jordan Sandstone in the extreme northwest part of the state (Figs. 4 and 6a). The Lower Ordovician Prairie du Chien Group comprises the Gunter Sandstone at the base followed by Oneota Dolomite, New Richmond Sandstone, and the Shakopee Dolomite (Figs. 4, 5, and 6).

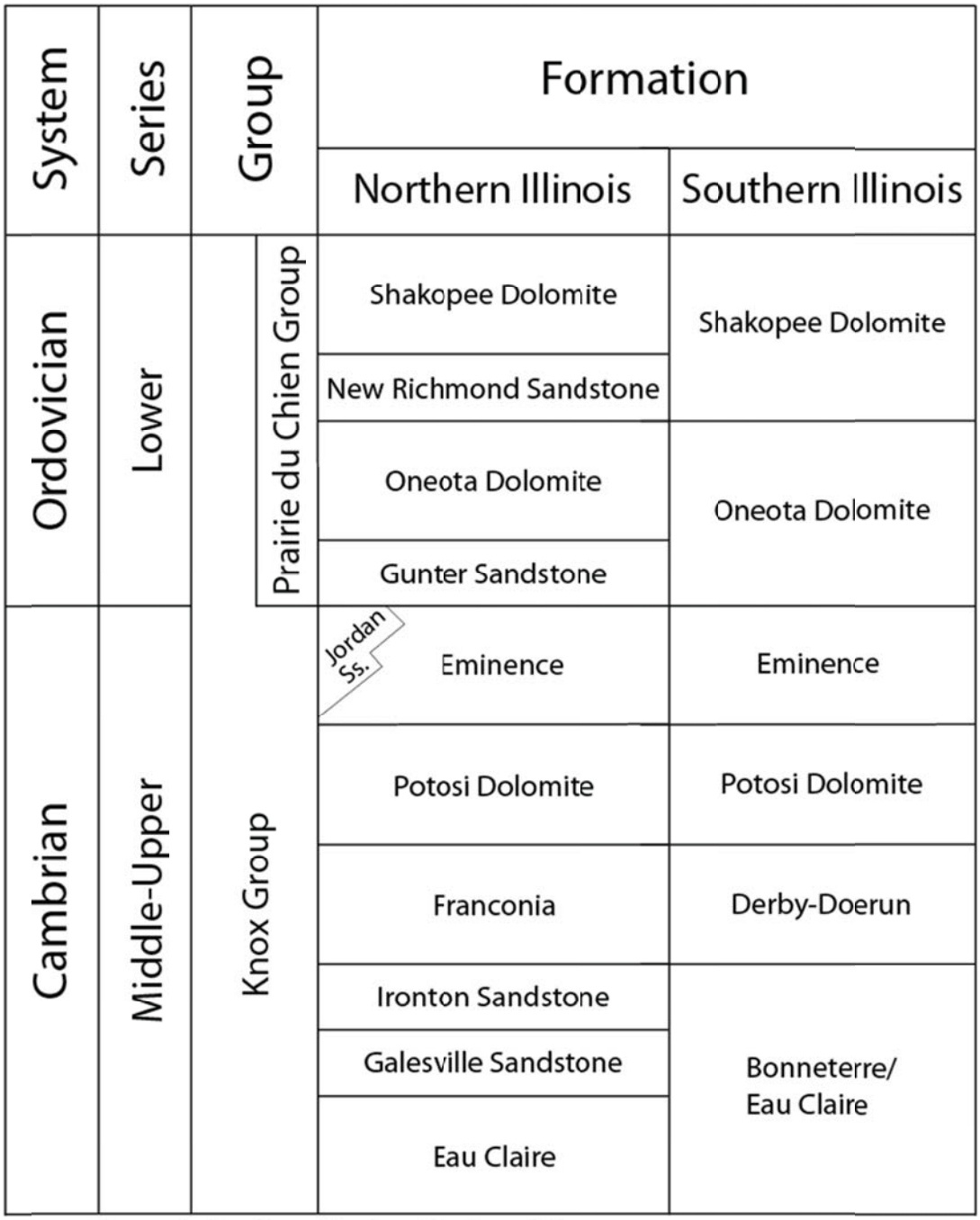


Figure 4: Stratigraphic classification of the Cambro-Ordovician Knox deposits in northern and southern Illinois.

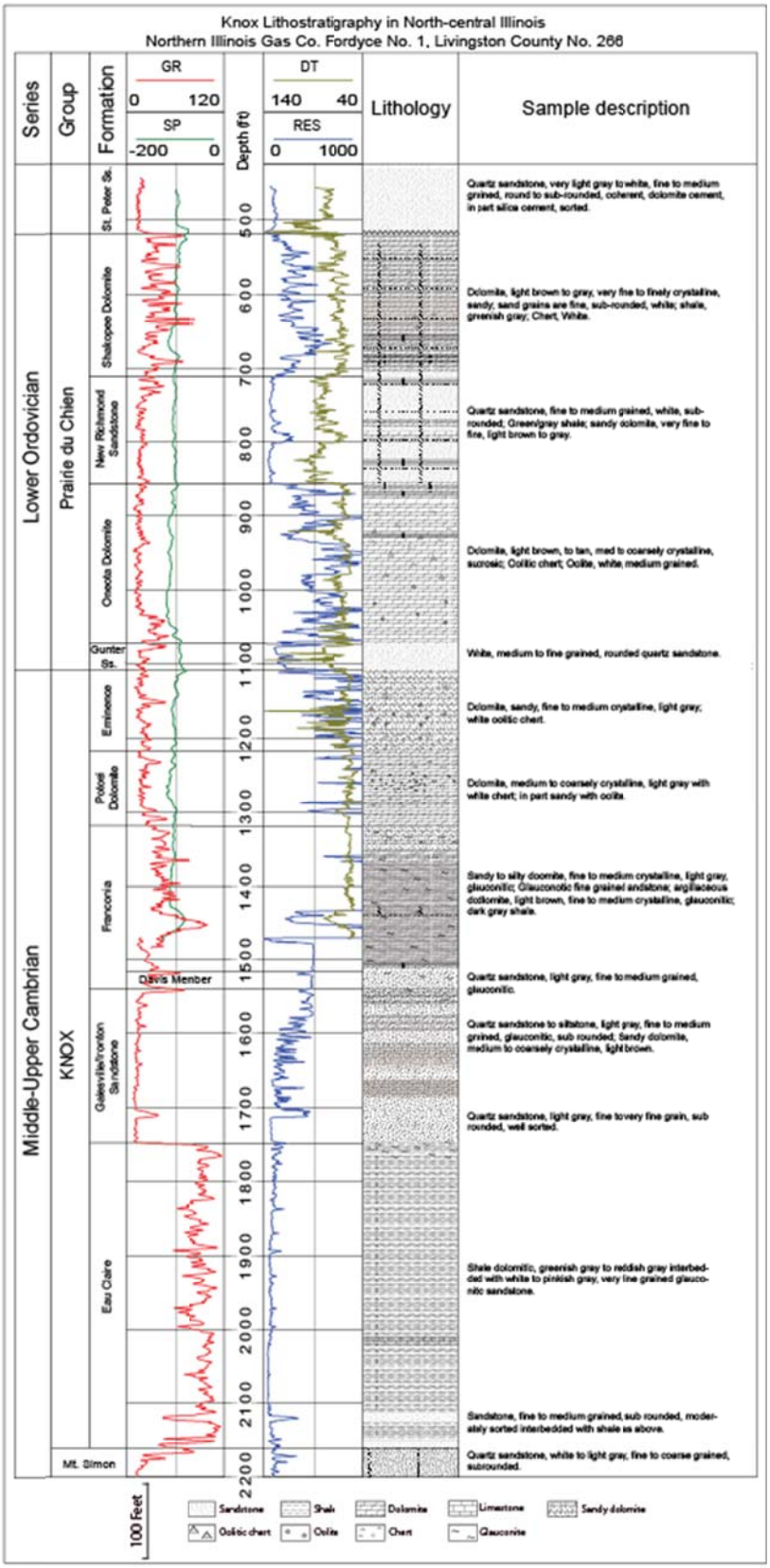


Figure 5: Type log of the Cambro-Ordovician Knox deposits in northern Illinois.

(See the appendix for high resolution figure)

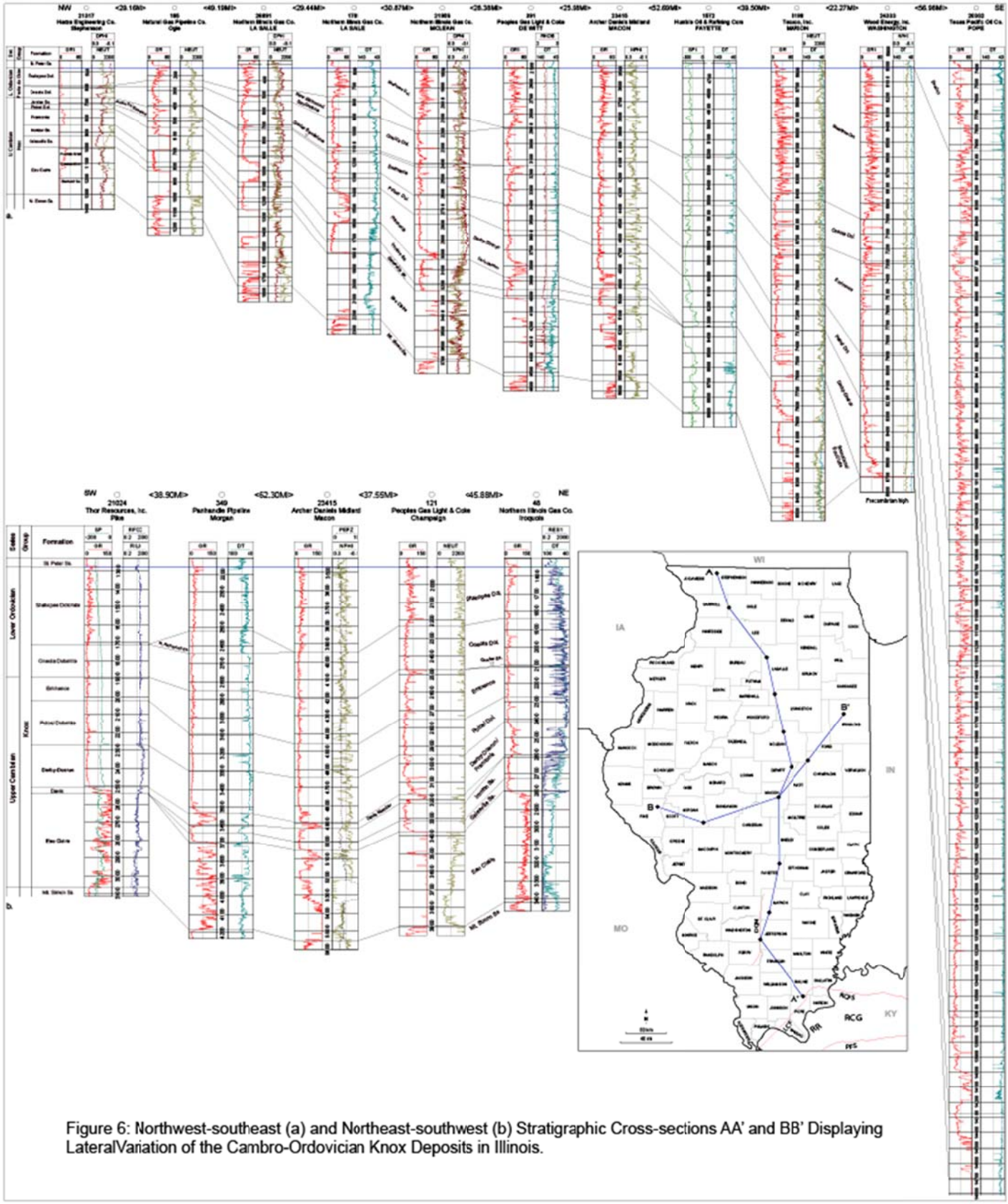


Figure 6: Northwest-southeast (a) and Northeast-southwest (b) Stratigraphic Cross-sections AA' and BB' Displaying LateralVariation of the Cambro-Ordovician Knox Deposits in Illinois.

The siliciclastic intervals thin southward and are absent in the southern and deeper part of the Illinois Basin (Figs. 6a and 7), where the contacts of the dominantly carbonate

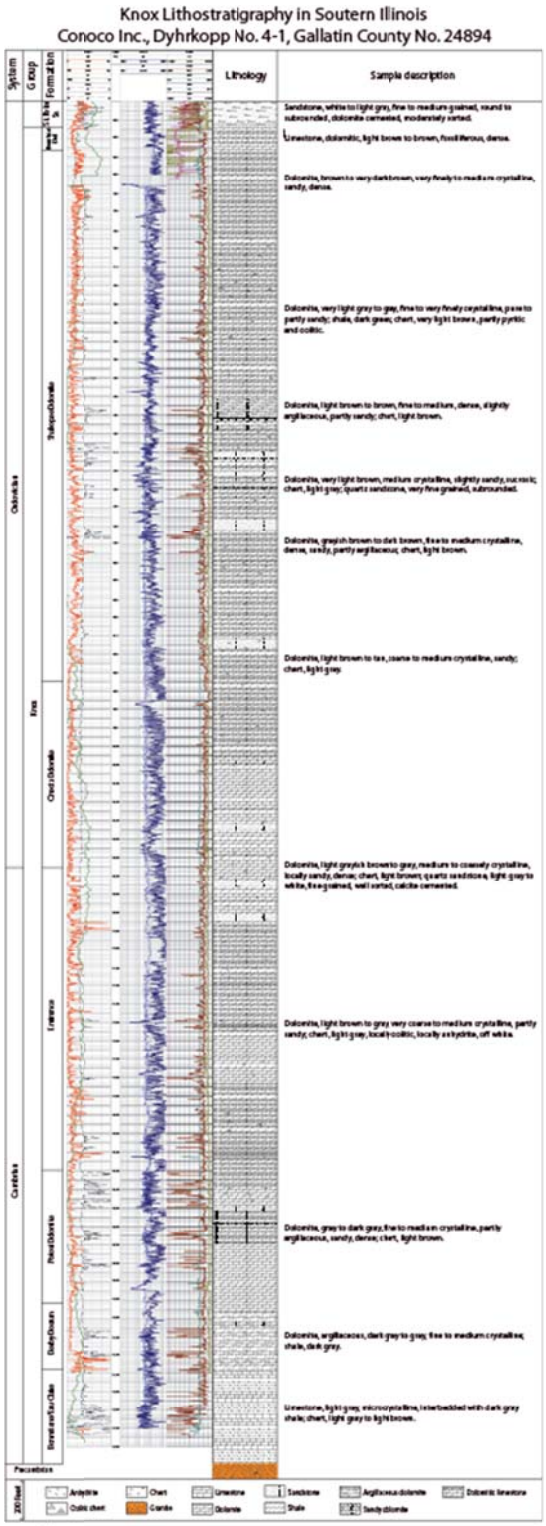


Figure 7: Type log of the Cambro-Ordovician Knox deposits in southern Illinois.

units cannot be determined with (See the appendix for high resolution figure)

confidence. Long regarded as the undifferentiated Knox Group, the Cambrian through Lower Ordovician succession in southern Illinois consists chiefly of fine to coarsely crystalline dolomite capped by the Middle Ordovician Everton Dolomite (Figs 6a and 7). Throughout the deposition of the Cambro-Ordovician deposits, the Illinois Basin was located in the equatorial region of the Lorentian continent (Fig. 3).

STRATIGRAPHY AND LITHOFACIES

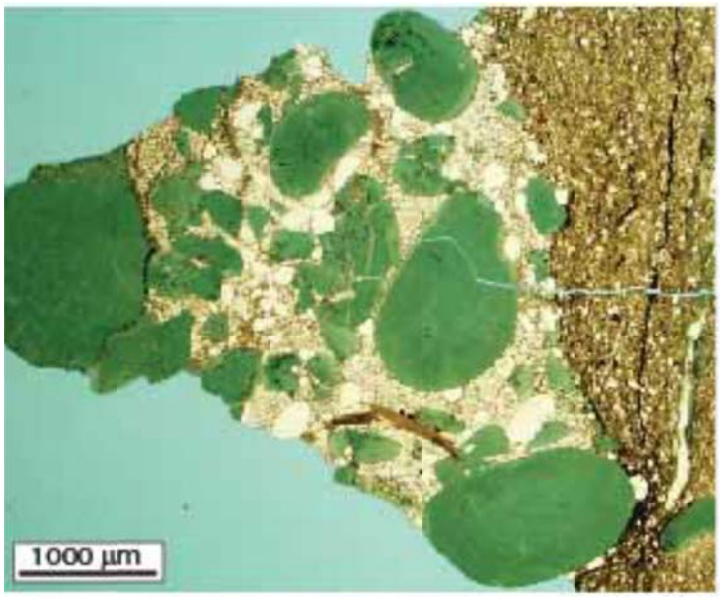
Detailed facies analysis indicates that the Cambrian through Lower Ordovician deposits in northern Illinois consist primarily of dolomite and sandstone with the lower part composed mainly of shale and siltstone. In southern Illinois, however, the succession is composed dominantly of dolomite with limestone and minor amounts of shale and sandstone forming the lower part of the Knox deposits.

Eau Claire/Bonneterre Formation

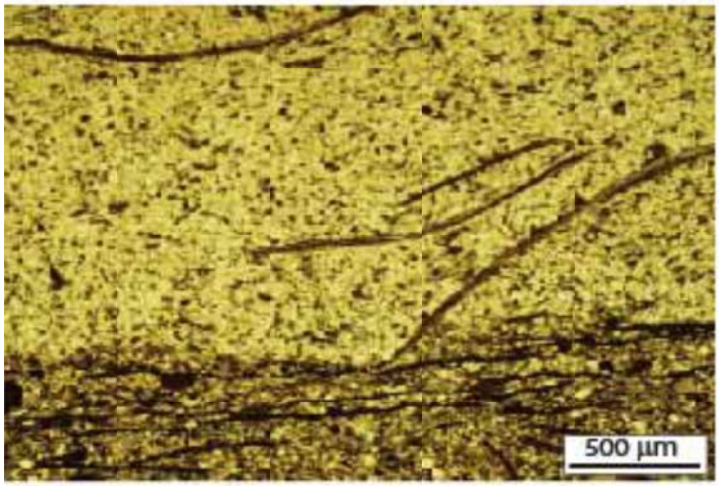
The Eau Claire Formation (upper Middle-lower Upper Cambrian) in the Illinois Basin is a dominantly siliciclastic succession and constitutes the upper part of the Sauk II subsrsequence. It is 300 feet thick in the extreme northwest of the state and thicken to over 600 feet in east central Illinois (Fig. 6). In the northern and central Illinois, it consists mainly of shale, siltstone, and sandstone with lesser amount of dolomite, overlying, with a gradational contact, the Mt. Simon Sandstone and underlying the clean Galesville Sandstone (Figs. 4 through 6). In northern Illinois, three members including, the Proviso Siltstone, Lombard Dolomite, and Elmhurst Sandstone Members (Buschbach, 1975) are recognized (see Fig. 6a, Stephenson County No. 21317). The sandstone and siltstone facies are commonly glauconitic and fossiliferous with phosphatic Lingulid brachiopod being abundant in the lower part of the formation (Fig. 8).

In southern Illinois, the Eau Claire grades to dominantly carbonate deposits of the Bonneterre Formation (Figs. 6 and 7), the lower part of which is characterized by interlayering of limestone and sandstone and underlies the mainly carbonate unit of the Derby-Doerun Formation. The limestone in the Bonneterre Formation consist of lime mudstone to graintone facies containing dominantly of bioclasts and ooids (Fig. 9) with intraclasts and peloids as minor constituents. Numerous small-scale shallowing-upward mudstone to grainstone cycles are recognized in the Bonneterre Formation (Fig. 10). The Eau Claire Formation and its equivalent Bonneterre Formation thicken southward but the Bonneterre is thin or absent on the Precambrian highs in southwestern Illinois (Fig. 6a).

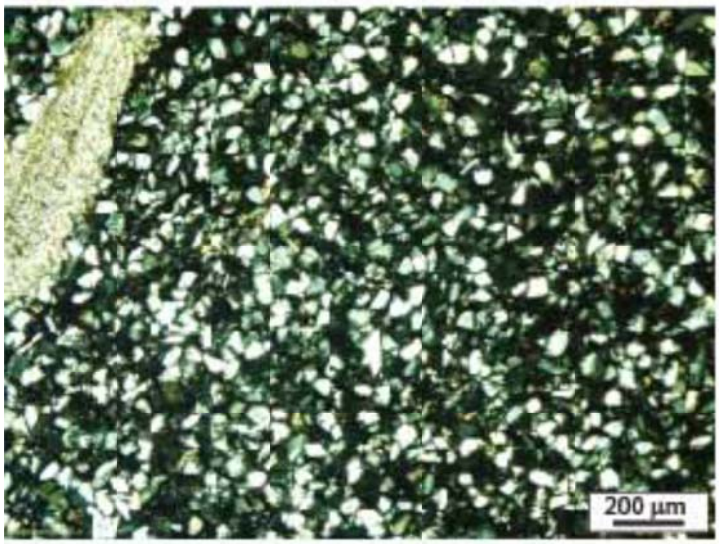
The Bonneterre was deposited along a southward-thickening carbonate platform; it thickens from less than 150 feet in the northwest of southern Illinois to over 3000 feet in the Rough Creek Graben of western Kentucky. Deposition of Bonneterre carbonates in



Interlayered glauconitic quartz sandstone and siltstone under plane light; Photomicrograph from Northern Illinois Gas Co. Fordyce No. 1, Livingston Co. IL; (depth 1800-05 ft).



Siltstone to very fine sandstone, fossiliferous (Lingula) under plane light; Thin section photomicrograph from Peoples Gas Light & Coke Co. Lamb No.1, Dewitt Co. IL; (depth 4500 ft).

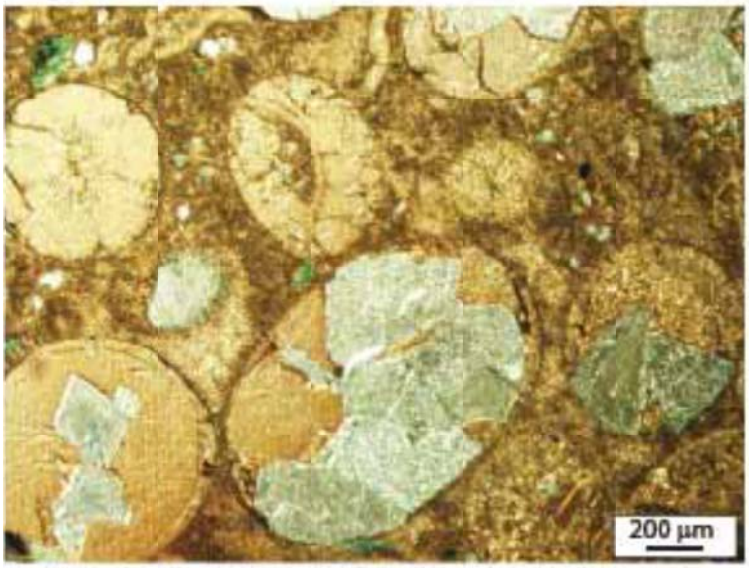


Siltstone to very fine grained glauconitic sandstone under polarized light. Note a shell fragment in the upper left from ADM CCS 1, Macon Co. IL; (depth 5,240-5,250 ft).

Figure 8: Photomicrographs of the Eau Clair Formation.

Fossiliferous lime mudstone to wackstone with trilobites, crinoids, pellets under plane light; Thin section photomicrograph from Conoco Inc. Dyhrkopp No. 4-1, Gallatin Co. IL; (depth13650-80 ft).

Ooid packstone showing relics of radial ooids under plain light. Note echinoderm fragments in left and a trilobite grain in the lower right of photograph from ADM CCS 1, Macon Co. IL; (depth 5100-5120 ft).



Siltstone to very fine grained glauconitic sandstone under polarized light. Note a shell fragment in the upper left from ADM CCS 1, Macon Co. IL; (depth 5,240-5,250 ft).

Figure 9: Photomicrographs of the Bonneterre Formation.

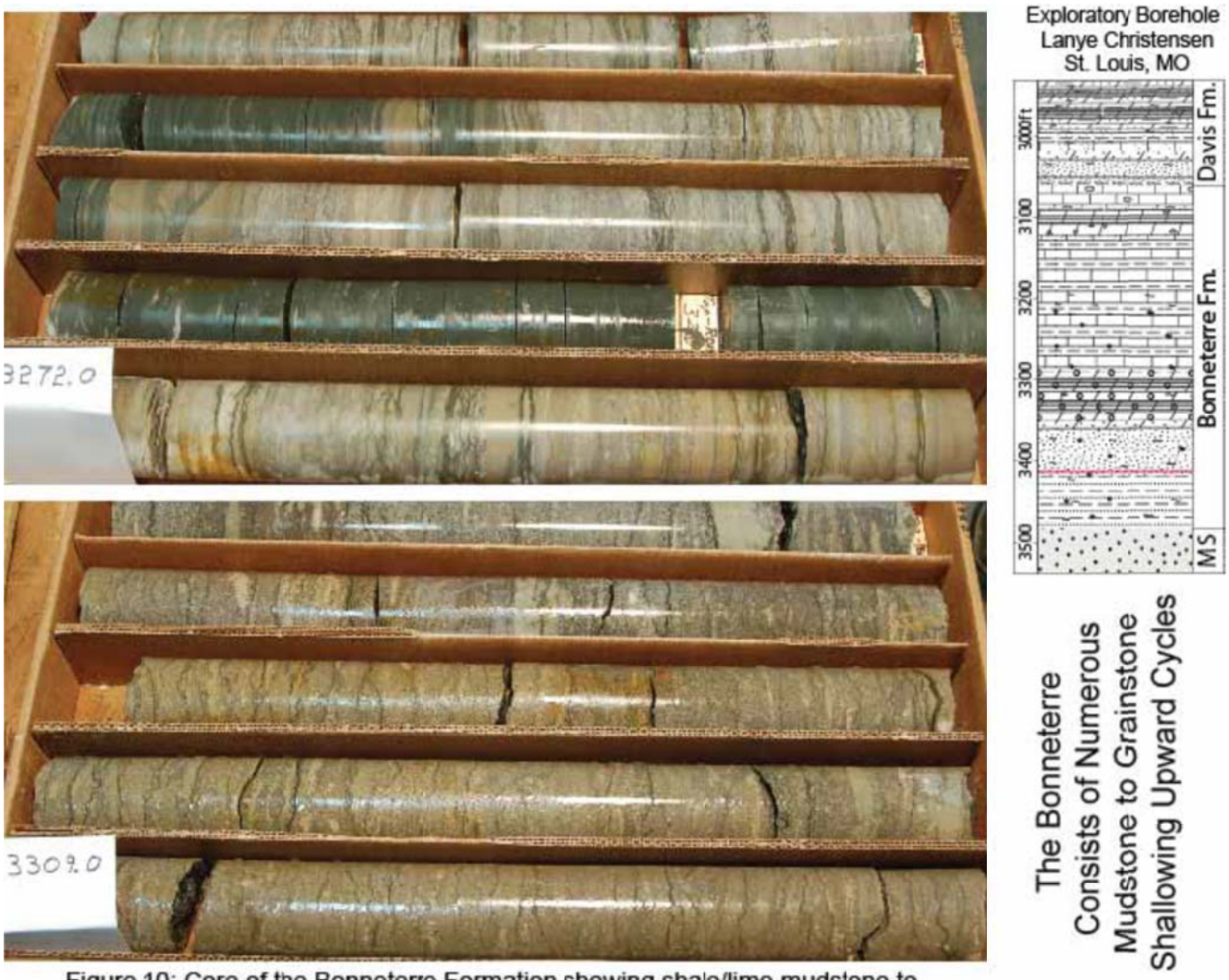


Figure 10: Core of the Bonneterre Formation showing shale/lime mudstone to grainstone facies.

the southern part of the Illinois Basin occurred when sea level rise during late Middle Cambrian resulted in the development of a vast carbonate platform and terrigenous sedimentation was confined to the northern part of the basin. The platform was developed along the northwest shoulder of the Reelfoot rift and adjacent craton, and is characterized by a platform margin that was facing the deep and rapidly subsiding Reelfoot-Rough Creek rift basin.

Galesville and Ironton Sandstones

The Galesville and Ironton Sandstones cover the northern half of Illinois (Fig. 11) and mark the upper part of the Sauk II subsequence. The Galesville (up to 100 feet thick) underlies, with a gradational contact, the dolomitic Ironton Sandstone and overlies, with a sharp contact, the Eau Clair Formation. It is a white, porous, and commonly friable, fine grained, mature quartzose sandstone (Fig. 12). The Ironton Sandstone (up to 100

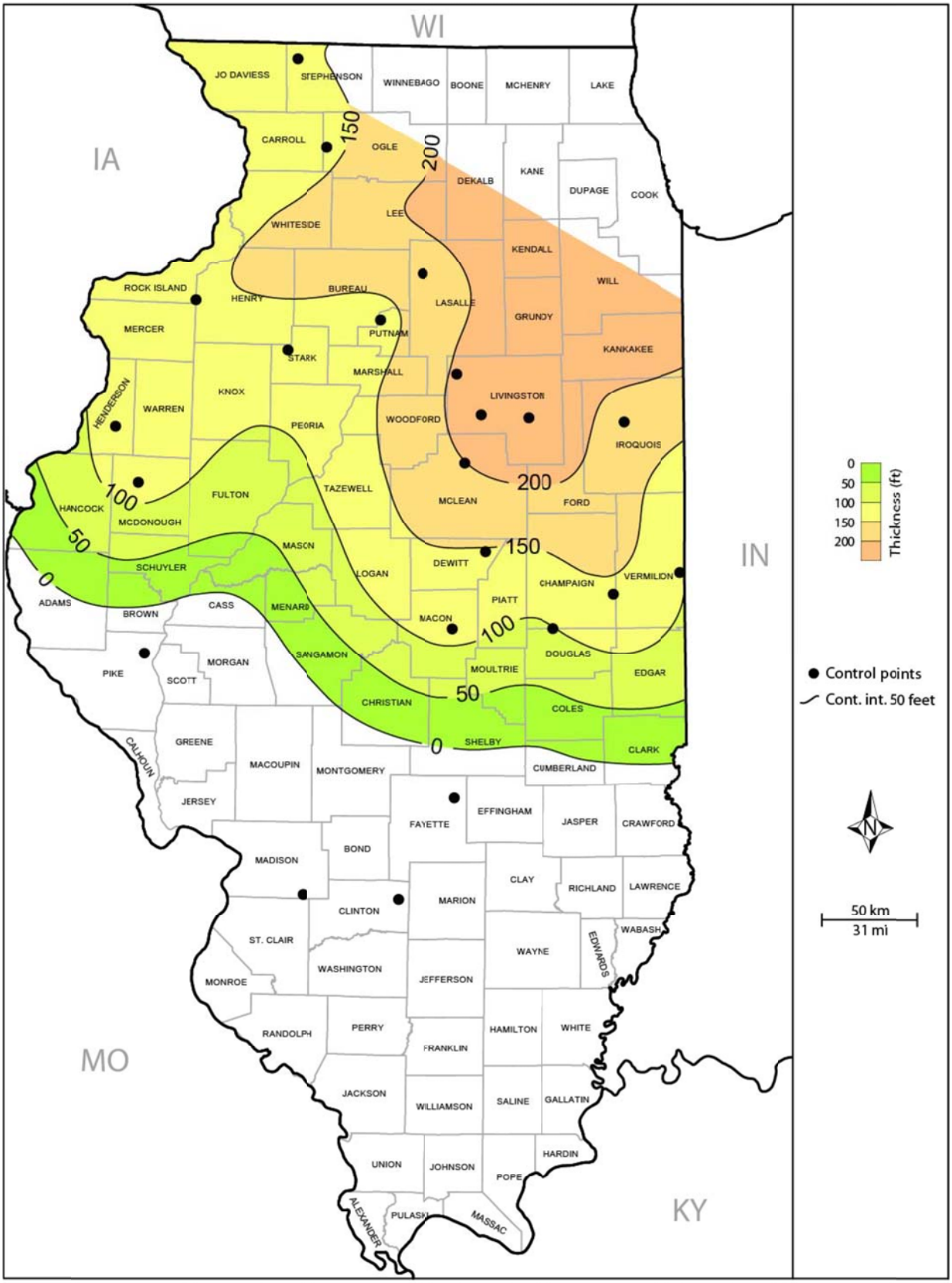
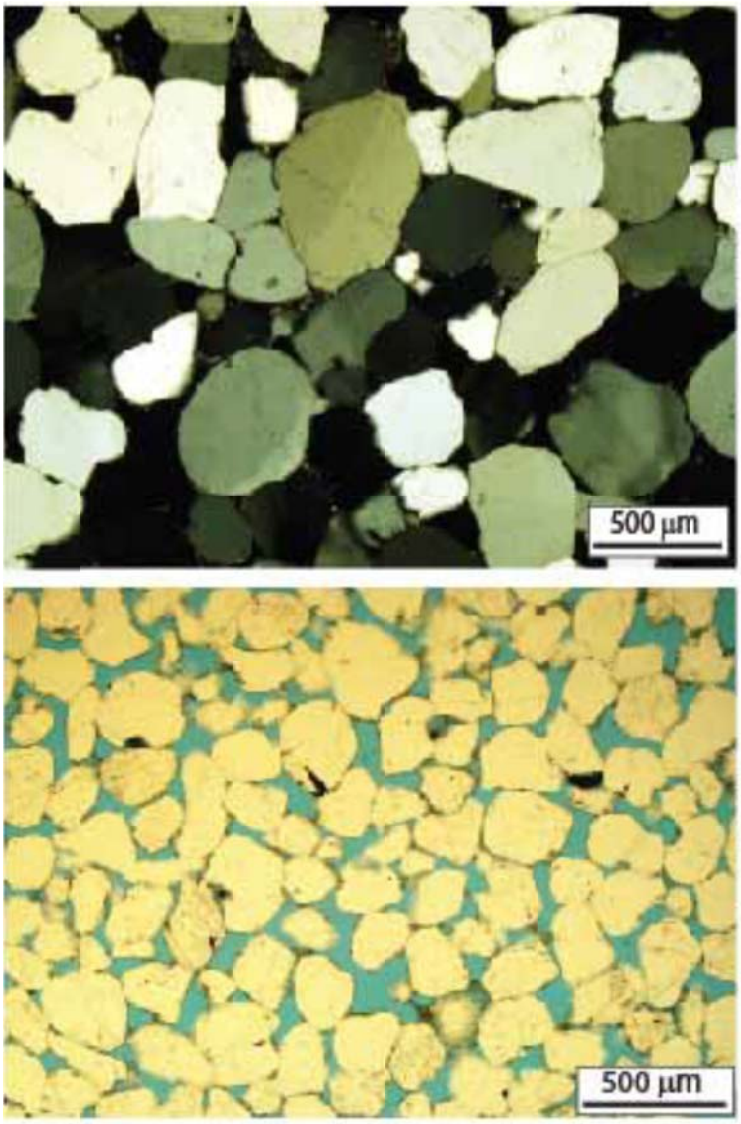


Figure 11: Isopach map of the combined Galesville and Ironton Sandstones.



Fine grained quartz sandstone with quartz and dolomite cement under polarized light. Thin section photomicrograph from Peoples Gas Light & Coke Co. Lamb No.1, Dewitt Co. IL; (depth 3971 ft).

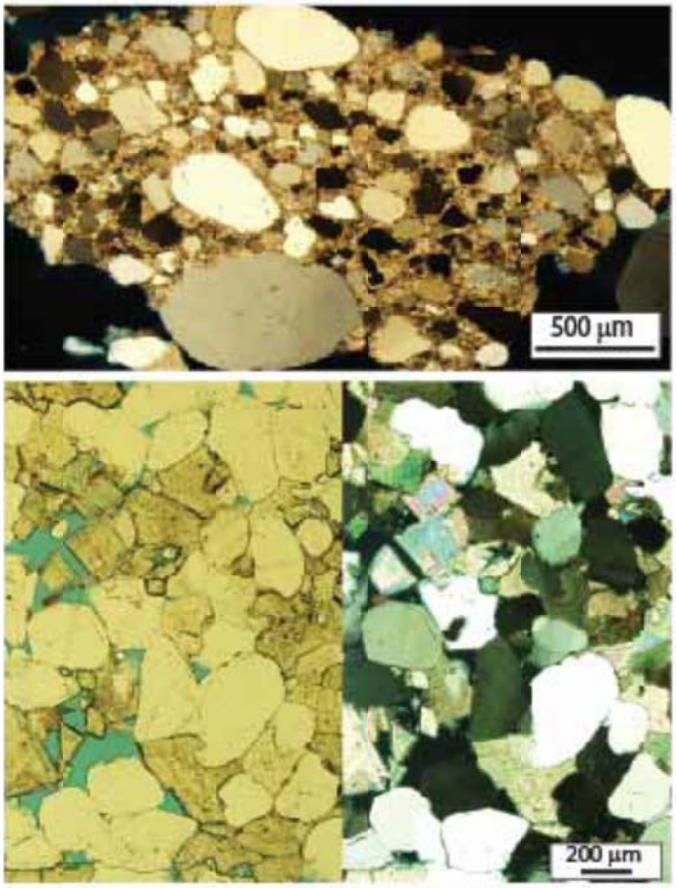
Fine grained porous quartz sandstone under plane light; Photomicrograph from Northern Illinois Gas Co. Fordyce No. 1, Livingston Co. IL; (depth 1710 -15 ft).

Figure 12: Photomicrographs of the Galesville Sandstone.

feet thick) is fine to coarse grained, commonly fossiliferous, porous quartzose sandstone that is interbedded with dense dolomitic sandstone or sandy dolomite (Fig. 13). It overlies the Galesville Sandstone and underlies the glauconitic Franconia Formation. The Ironton and Galesville Sandstones thin southwestward and grade to dolomite and sandy dolomite of the upper part of the Bonneterre Formation (Fig. 6a).

Franconia/Derby Doerun Formation

The Franconia Formation comprises the lower part of the Sauk III subsequence and underlies the relatively pure Potosi Dolomite. It consists of glauconitic sandstone, shale,



Fine to medium grained quartz sandstone with dolomite cement under polarized light; Thin section photomicrograph from Vickery Drilling Co., Inc., Mathesius No.1, LaSalle Co. IL; (depth 810-15 ft).

Medium to coarse grained quartz sandstone under polarized and plain light. Note quartz cement partial replacement of quarts by dolomite crystals (depth 4,970 ft).

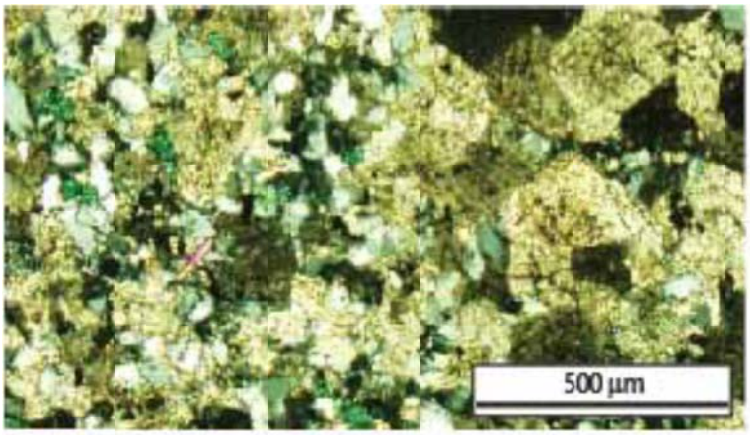
Figure 13: Photomicrographs of the Ironton Sandstone.

and sandy dolomite (Fig. 14). The formation thickens southward from nearly 100 feet in the far northwest of the state to over 600 feet in southern Illinois (Fig. 6). In the extreme northern area of Illinois, the Franconia Formation consists of interbedded glauconitic sandstone and shale (Buschbach, 1975) (see Stephenson and Ogle County wells in Fig. 6a). Southward a distinct upper sandy dolomite member (Derby-Doerun) and a lower shaly, glauconitic quartz sandstone (Davis Member) can be differentiated (Figs. 6 and 14). In southern Illinois, the formation consists predominantly of dolomite and it is referred to as Derby-Doerun Formation. The Member is equivalent of Davis Formation of southern Missouri, which consists of carbonates, glauconitic sandstone and shale (Fig. 15).

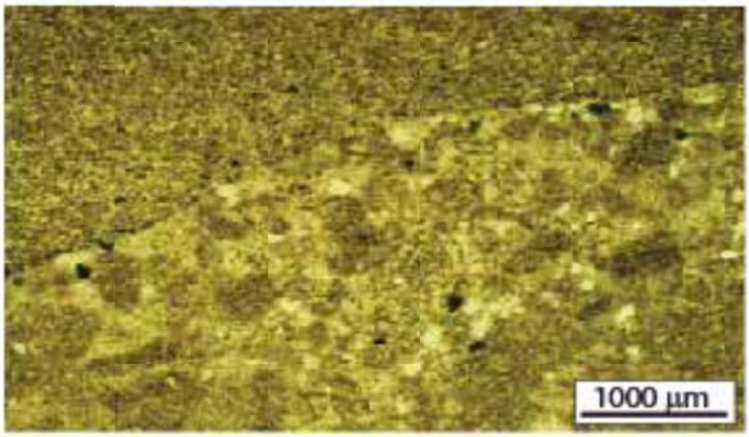
Potosi Dolomite

The Upper Cambrian Potosi is a relatively pure dolomite unit that underlies and overlies the relatively impure Eminence and Franconia Formations, respectively. Recognition of the Potosi-Eminence contact in the field is difficult because in many areas their boundary are characterized by gradational interbedded Potosi and Eminence lithologies (Miller et al., 2013). In the subsurface, however, geophysical logs indicate that the

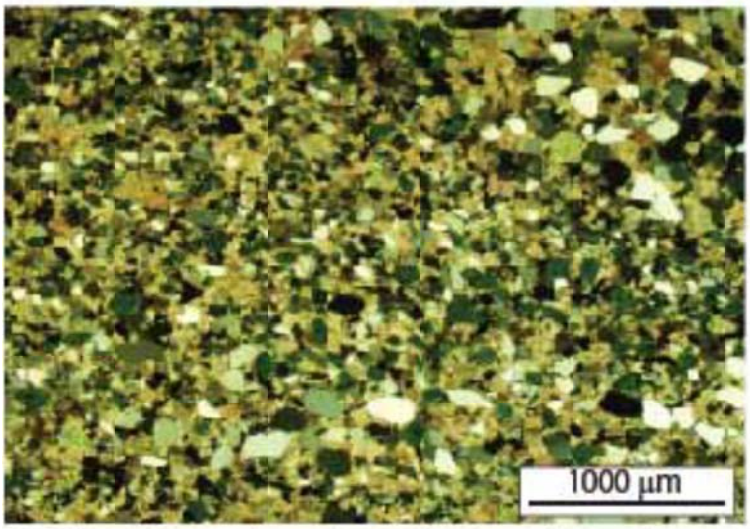
Potosi is less radioactive and more resistant than the Eminence Formation (Figs. 5 through 7). Thickness of the Potosi Dolomite ranges from less than 50 feet in northwest Illinois to over 600 feet in southern Illinois. It is a fine to coarsely crystalline dolomite with relics of bioclasts, ooids, and peloids. The Potosi is commonly dense but it is locally



Sandy glauconitic, fine to medium crystalline dolomite; under polarized light; Thin section photomicrograph from Texaco Inc. Johnson No. 1, Marion Co. IL; (depth 7470-75 ft).



Sandy, fine to medium crystalline dolomite with relics of fossils and pellet under plane light; Thin section photomicrograph from Peoples Gas Light & Coke Co. Lamb No.1, Dewitt Co. IL; (depth 3744 ft).



Dolomite cemented glauconitic quartz sandstone (Davis Member) under polarized light; Thin section photomicrograph from Peoples Gas Light & Coke Co., Lamb No.1, Dewitt Co. IL; (depth 3821 ft).

Figure 14: Photomicrographs of the Franconia Formation.

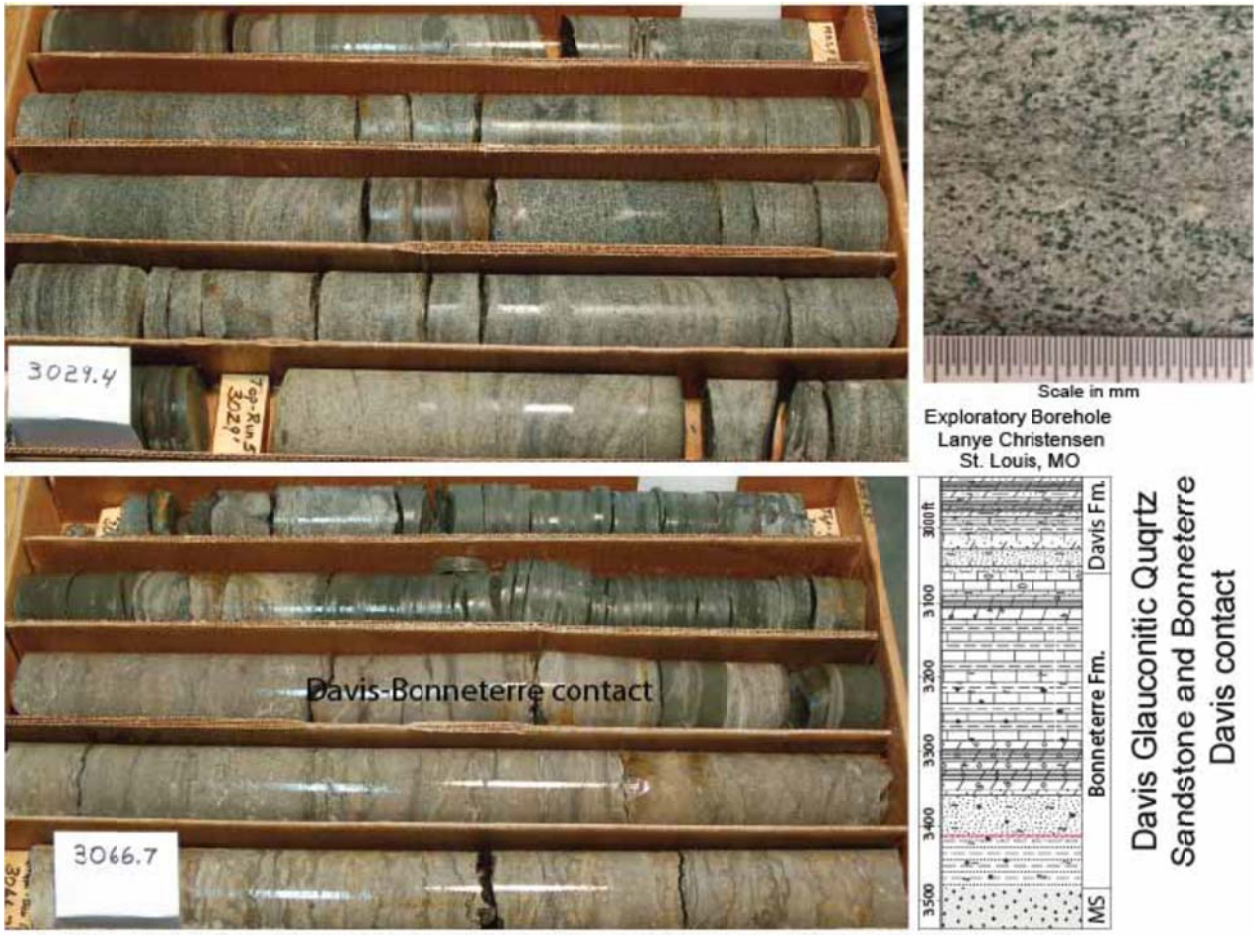
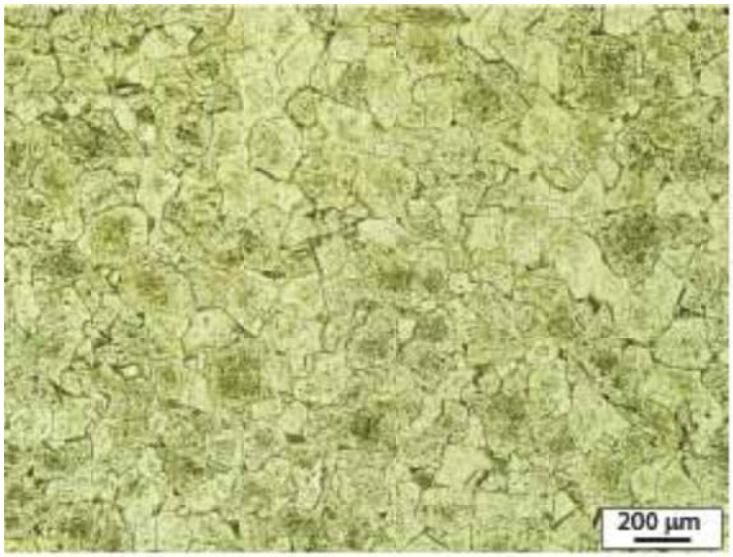


Figure 15: Core Photograph showing the Davis Sandstone and its contact with the Bonneterre Formation.

vugular and fractured with the cavity surface covered by drusy quartz (Figs. 16 through 18).

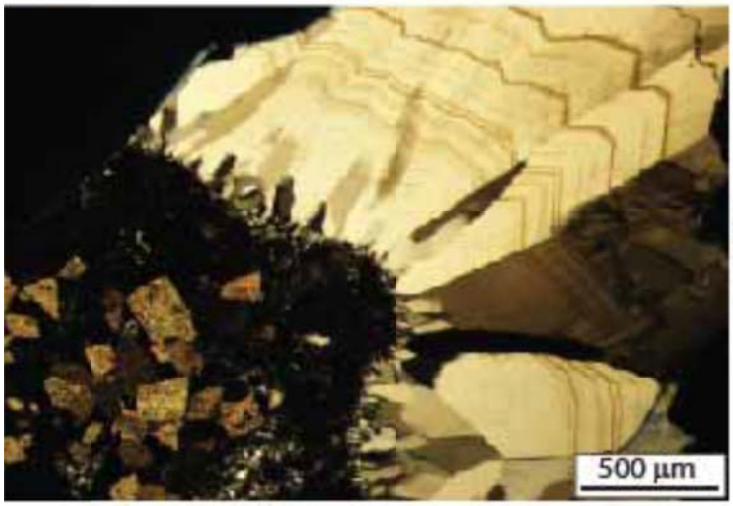
Eminence Formation

The uppermost Cambrian Eminence Formation is a sandy dolomite and conformably underlies the relatively pure Potosi Dolomite. It underlies the lowermost Ordovician Gunter Sandstone or the Oneota Dolomite where the Gunter is absent (Figs. 5 through 7). The sand content increases northward and in the extreme northwestern Illinois, the Eminence grades to quartzose sandstone of the Jordan Sandstone (Fig. 6a). A basal discontinuous sandstone member, the Momence Member, is present in parts of northern Illinois (Buschbach, 1975). The Eminence is over 50 feet thick in northern Illinois and reaches a thickness of over 1400 feet in southern Illinois (Fig. 6). The Eminence Formation is relatively argillaceous and thin sandstone, siltstone or shale beds are present throughout the formation (Fig. 19) even in the deeper part of the Illinois Basin in southern Illinois. It consists of sandy very fine to medium crystalline dolomite with ooids, bioclasts, peloids and intraclasts as relics in the dolomite or



Dense medium crystalline dolomite with relics of pellets under plain light (depth 4,490 ft).

Hand sample of drusy quartz in the Potosi dolomite. Junction Highways 21 and 47, south of Potosi, MO.



Thin section photomicrograph of drusy quartz in a fine to coarsely crystalline dolomite under polarized light; Vickery Drilling Co., Inc., Mathesius No.1, LaSalle Co. IL; (depth 550-55 ft).

Figure 16: Photomicrographs of the Potosi Dolomite.

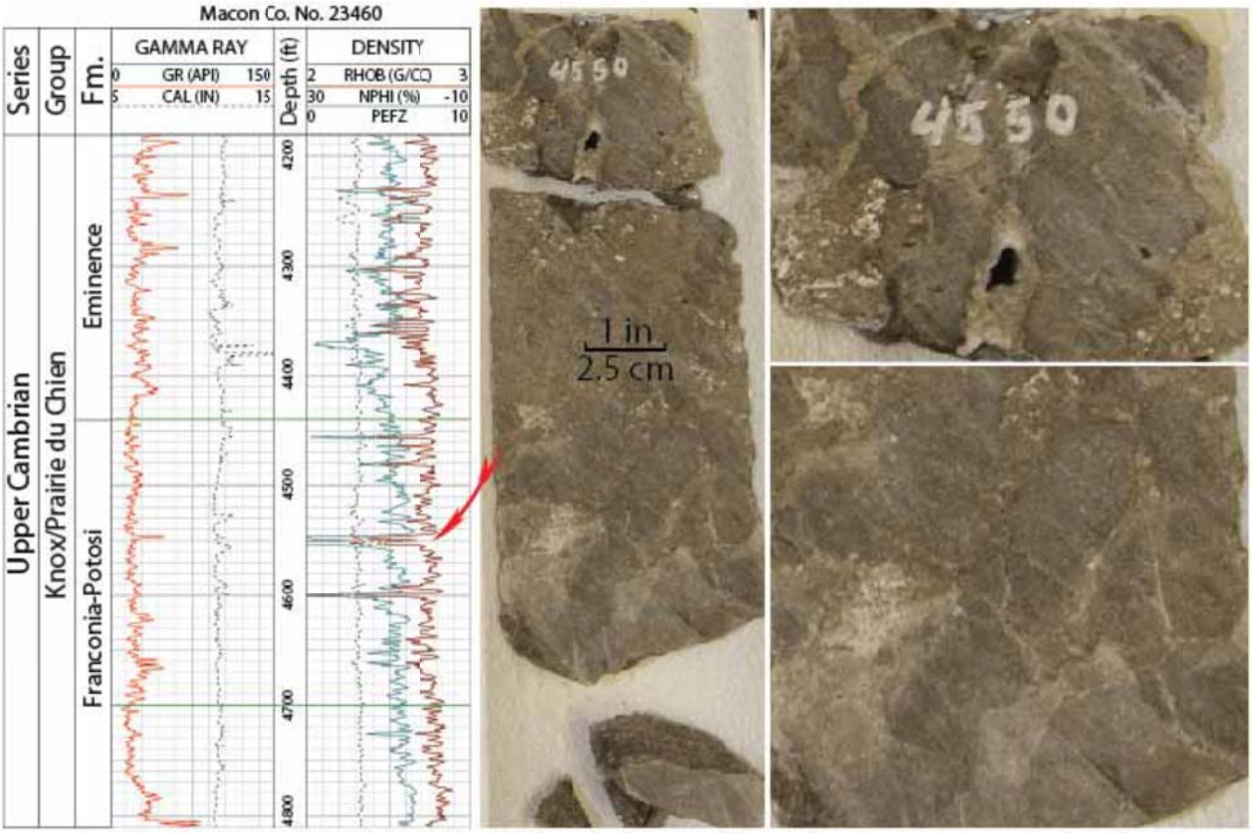


Figure 17: Fracture and cavernous porosity in the Potosi Dolomite in which several hundred barrels of drilling fluid was lost.

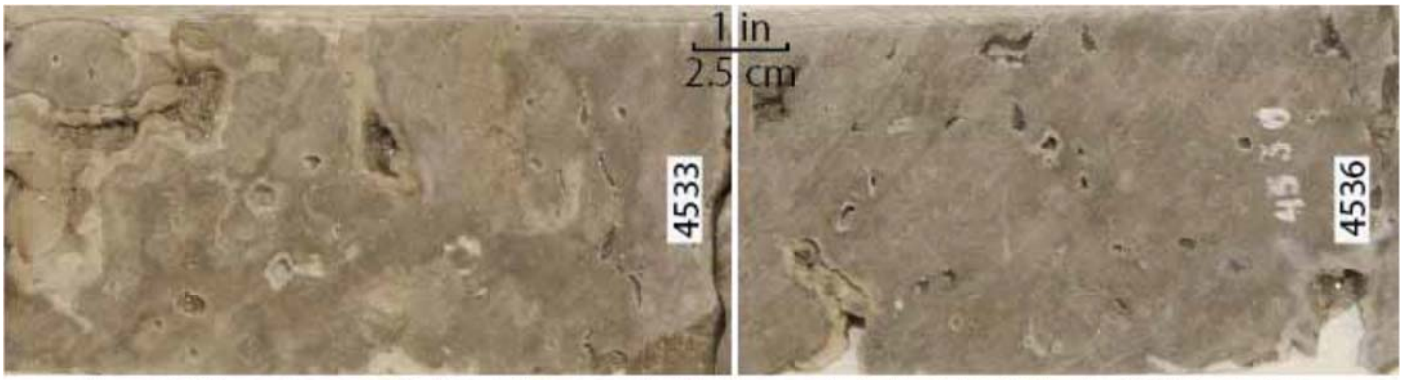


Figure 18: Vuggy porosity with the cavities covered with drusy quarts in the Potosi Dolomite; ADM Verification, Macon Co. IL.

preserved grains in chert nodules (Fig. 20). Although less abundant, similar to Potosi Dolomite, small drusy quartz lined cavities are present. Fracture and vugular porosity are locally present in the dense dolomite of the Eminence Formation (Fig. 21).

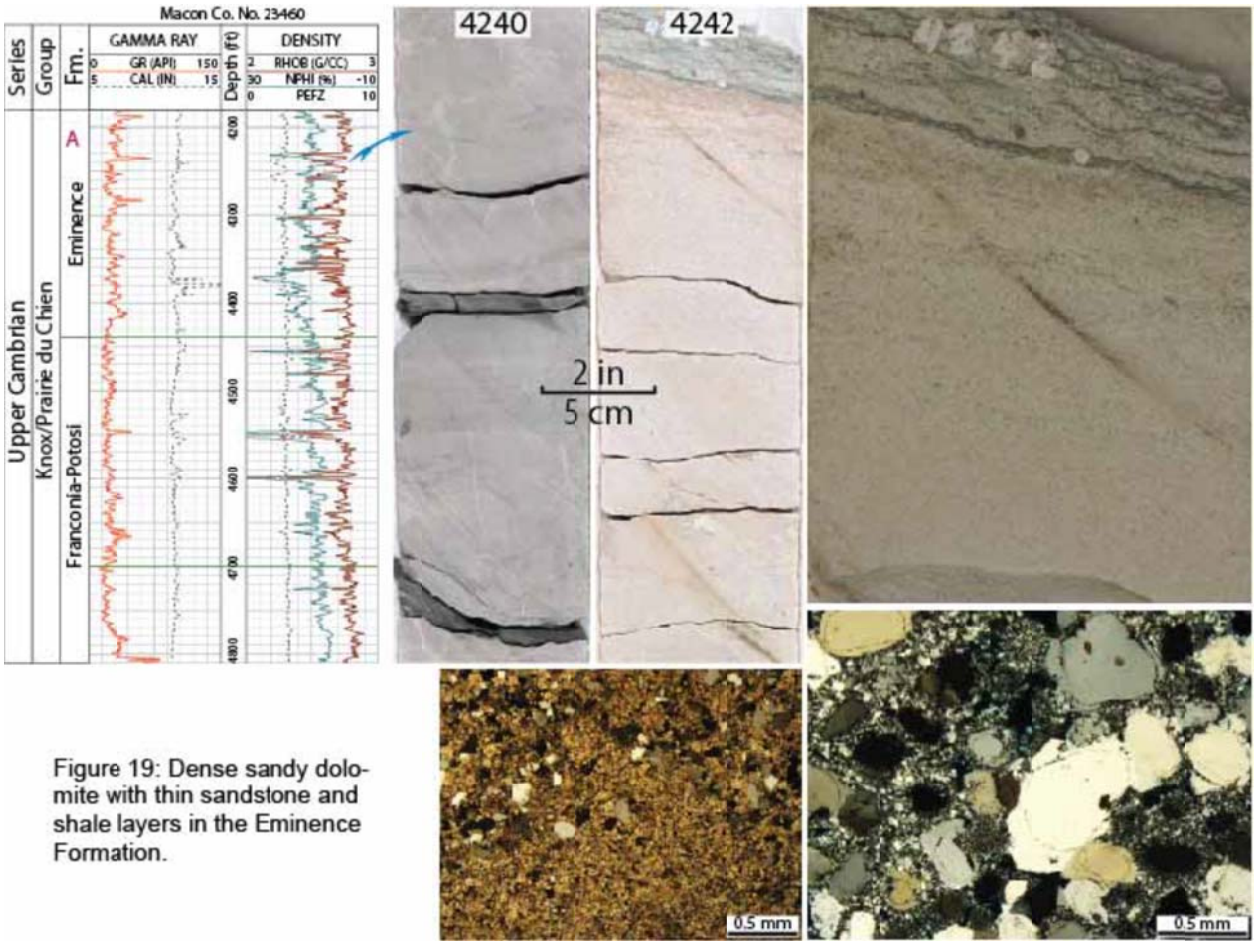


Figure 19: Dense sandy dolomite with thin sandstone and shale layers in the Eminence Formation.

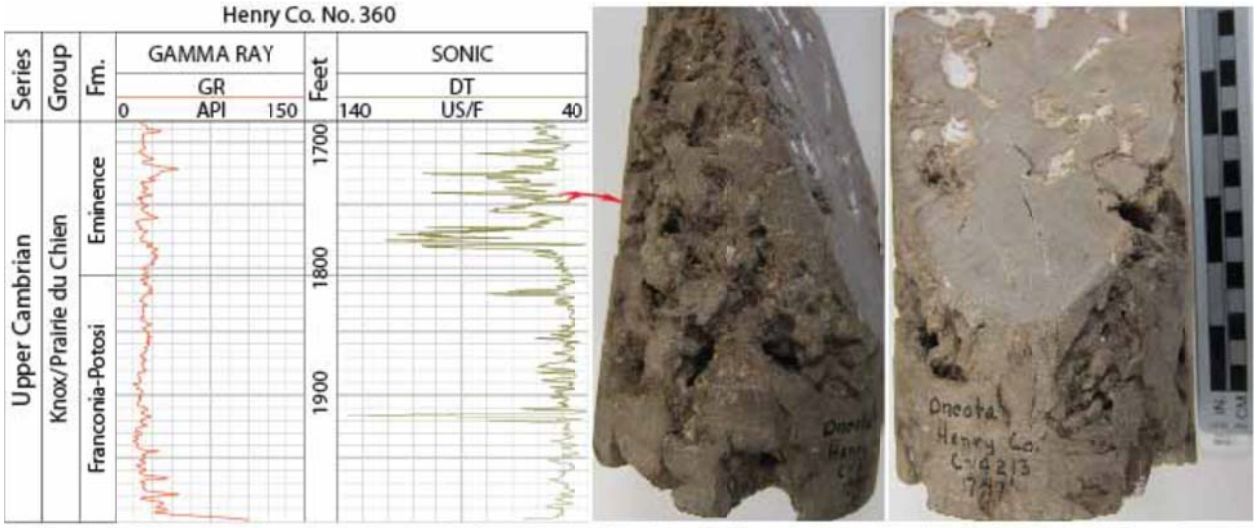
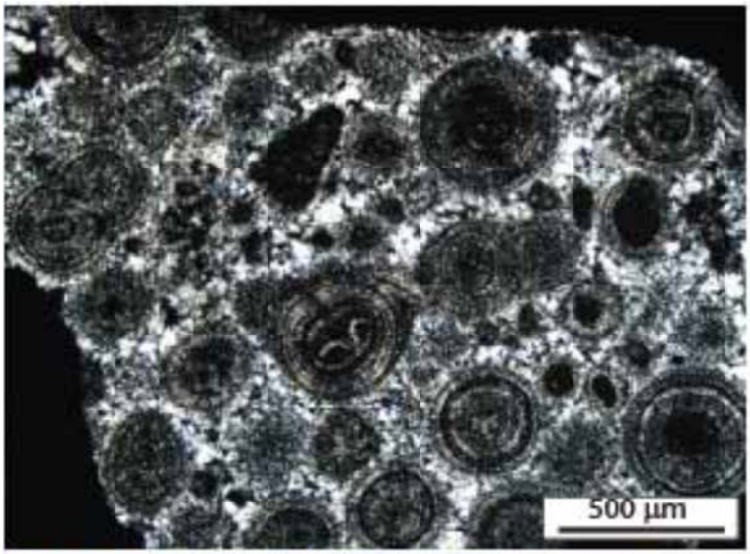
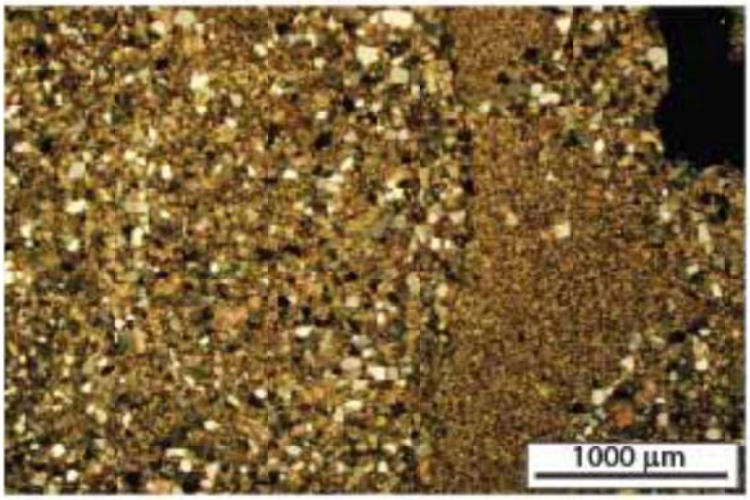


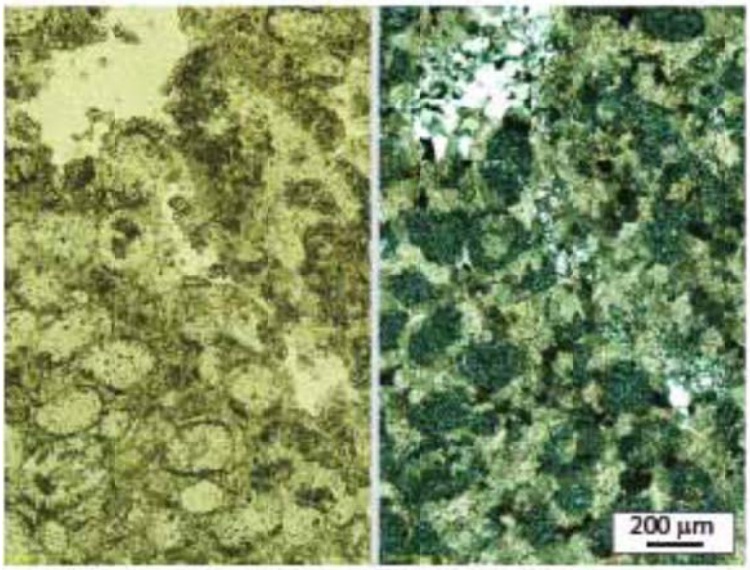
Figure 20: Vugular and cavernous porosity in the dolomite of the Eminence Formation in which drilling fluid was lost during drilling.



Cherified oolitic grainstone under polarized light; Thin section photomicrograph from Humble Oil and Refining Co. Weaber-Horn Unit No.1, Fayette Co. IL; (depth 5690-95 ft).



Finely crystalline sandy dolomite and fine grained sandstone under polarized light; Thin section photomicrograph from Vickery Drilling Co., Inc., Mathesius No.1, LaSalle Co. IL; (depth 540-45 ft).



Finely crystalline dolomite, with goast of peloid, and ooids under polarized and plain light. Note partial silicification in the upper left corner of the photograph from ADM CCS1, Macon Co. IL; (depth 4,400-4,450 ft).

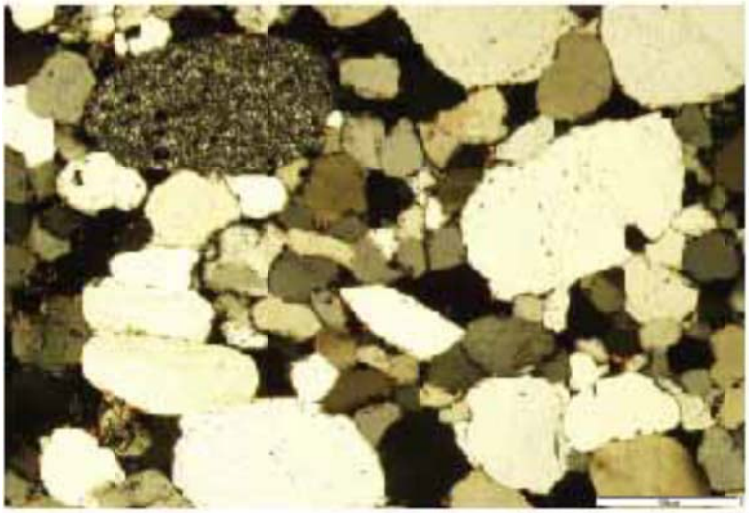
Figure 21: Photomicrographs of the Eminence Formation.

Gunter Sandstone and Oneota Dolomite

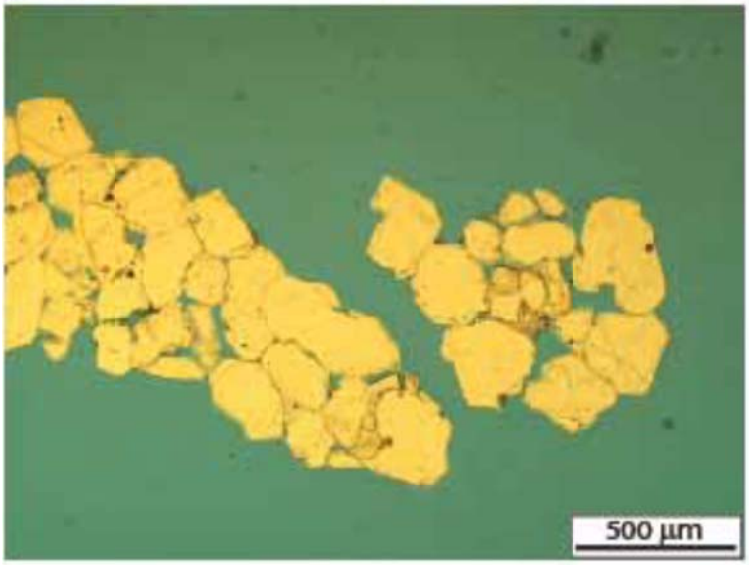
The lowermost Ordovician Gunter Sandstone overlies the Eminence, with a sharp contact, the Eminence Formation (Fig. 22) and grades upward to Oneota Dolomite. The Gunter (up to 25 feet thick) covers part of north-central Illinois and commonly is a fine to medium grained, mature to supermature quartzarenite (Figs. 22 and 23). Thin beds of sandy dolomite may occur in the upper part of the Gunter Sandstone.

The Oneota Dolomite is less than 100 feet in northern Illinois, thickening to nearly 250 feet in central region, and to over 800 feet in southern Illinois (Fig. 6). It underlies the New Richmond Sandstone in the northwestern half of Illinois and the Shakopee Dolomite in the rest of the state. The Oneota Dolomite consists of fine to coarsely crystalline dolomite with ooids, peloids, intraclasts, and bioclasts as relics in dolomite or as preserved grains in chert nodules (Fig. 24). The commonly dense Oneota dolomite is locally fractured or may display intercrystalline pore spaces (Fig. 24).

Figure 22: Photograph showing the sharp contact between the massive dolomite of the Eminence Formation and the basal Ordovician Gunter Sandstone (left) and close-up photograph of fine to coarse grained supermature bimodal quartz sandstone of the Gunter Sandstone; Colosseum Trail, Ha Ha Tonka State Park, Missouri.



Thin section photomicrograph of fine to coarse grained, well-rounded bimodal quartz arenite under polarized light; Road cut along Highway 5, MO.



Fine to medium grained, porous mature quartz sandstone under plane and polarized light; Thin section photomicrograph from Northern Illinois Gas Co., Fordyce No.1, Livingston Co., IL; (depth 1100-05 ft).

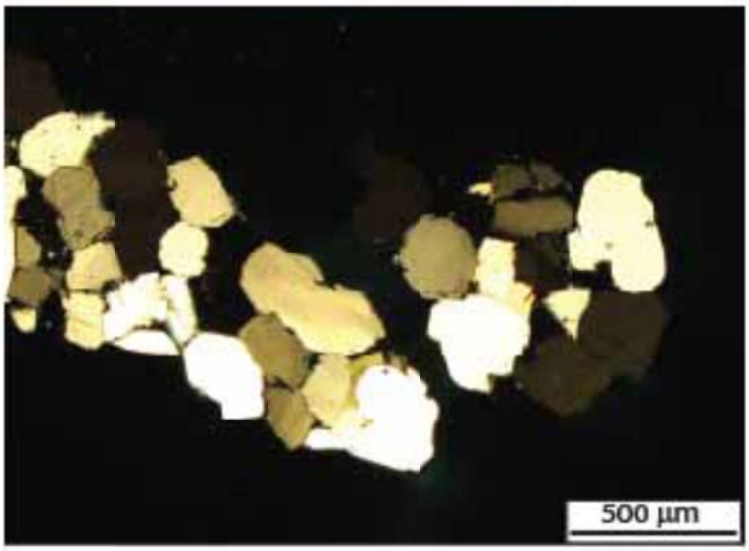
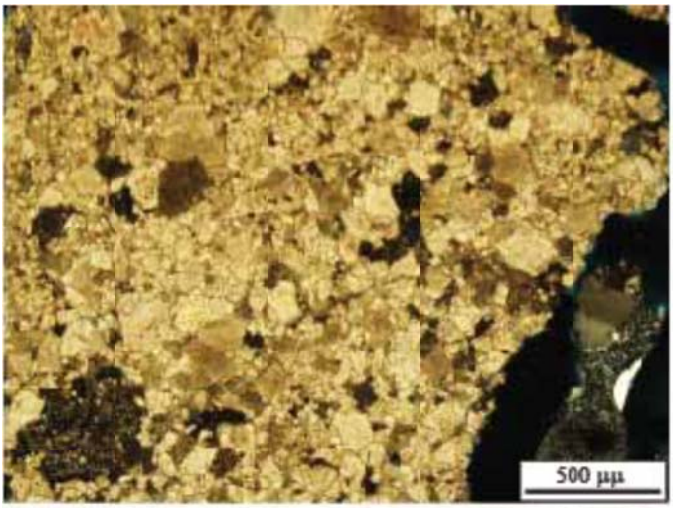
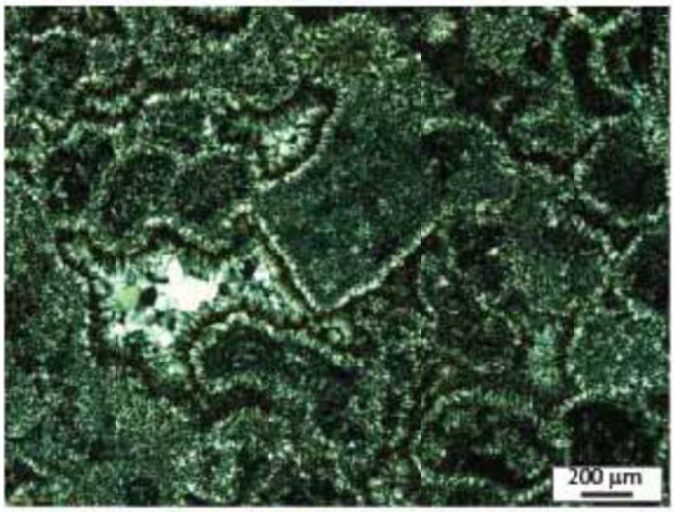


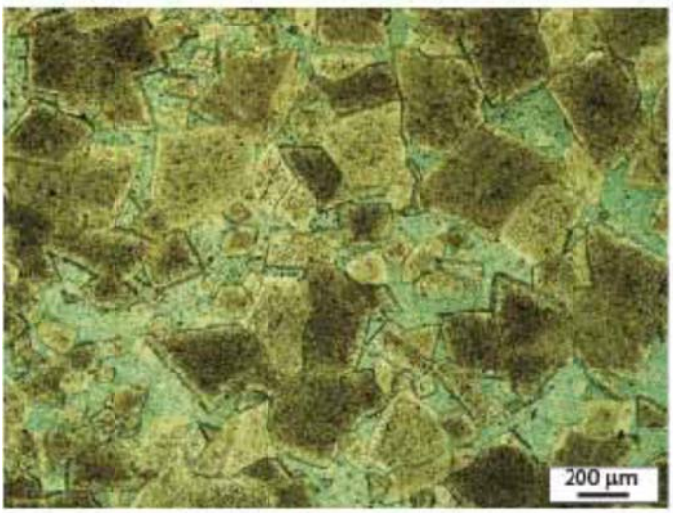
Figure 23: Photomicrographs of the Gunter Sandstone.



Fine to medium crystalline dense dolomite with relics of bioclasts and ooids under polarized light from Northern Illinois Gas Co. Fordyce No. 1, Livingston Co. IL (depth 880-890 ft).



Silicified grainstone facies showing relicts of ooid, crinoid, and intraclast under polarized light from ADM CCS1, Macon Co. IL (depth 4,020-4,030 ft).



Medium crystalline porous sucrosic dolimite under plain light showing inter-crystalline porosity from ADM CCS1, Macon Co. IL (depth 4,090-4100 ft).

Figure 24: Photomicrographs of the Oneota

New Richmond Sandstone and Shakopee Dolomite

The New Richmond Sandstone gradationally underlies the Shakopee dolomite and sharply overlies the Oneota Dolomite. It is present in the northwestern half of the state (Fig. 25) and its thickness ranges from less than 20 feet in northwestern Illinois to over

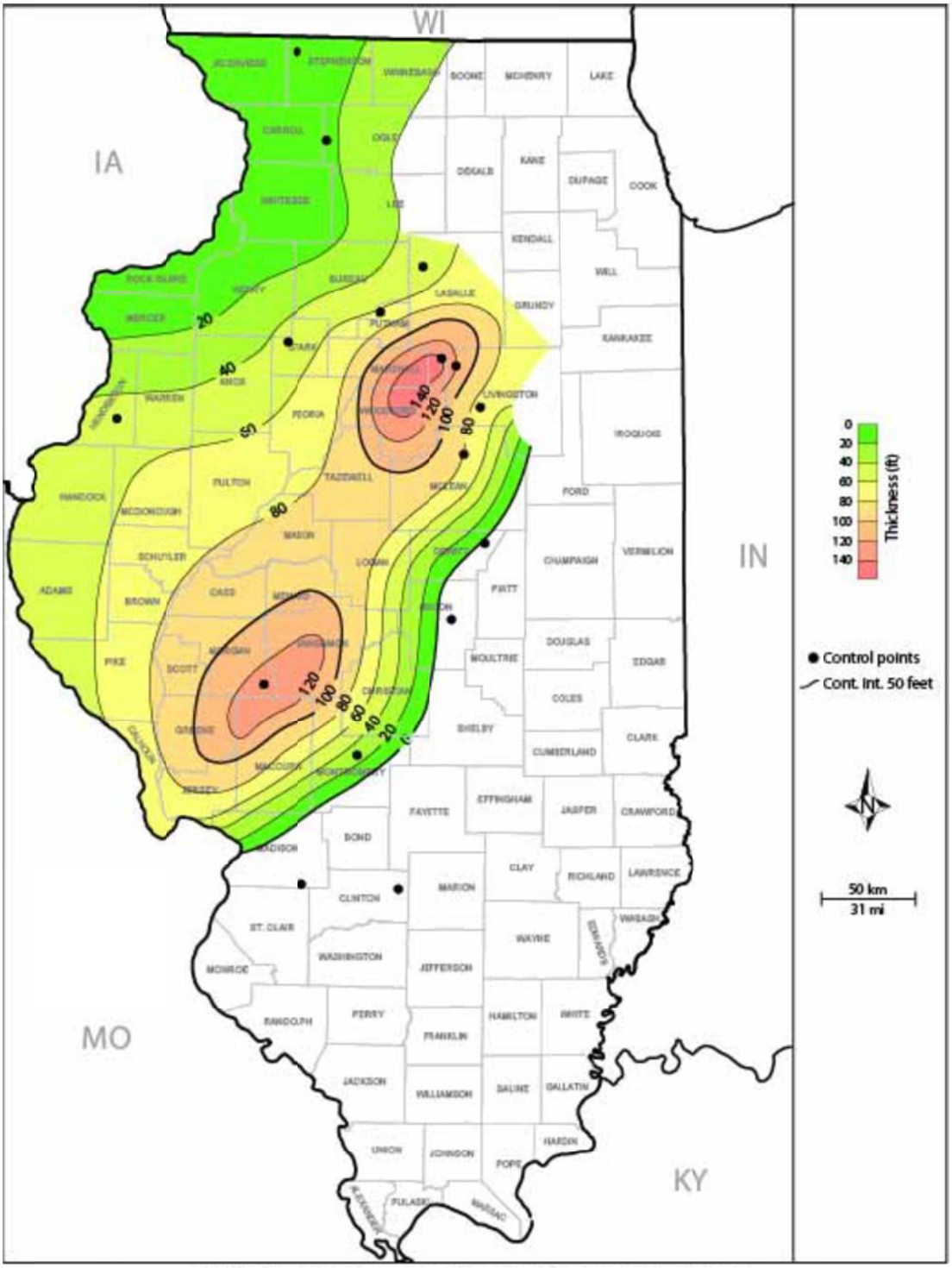
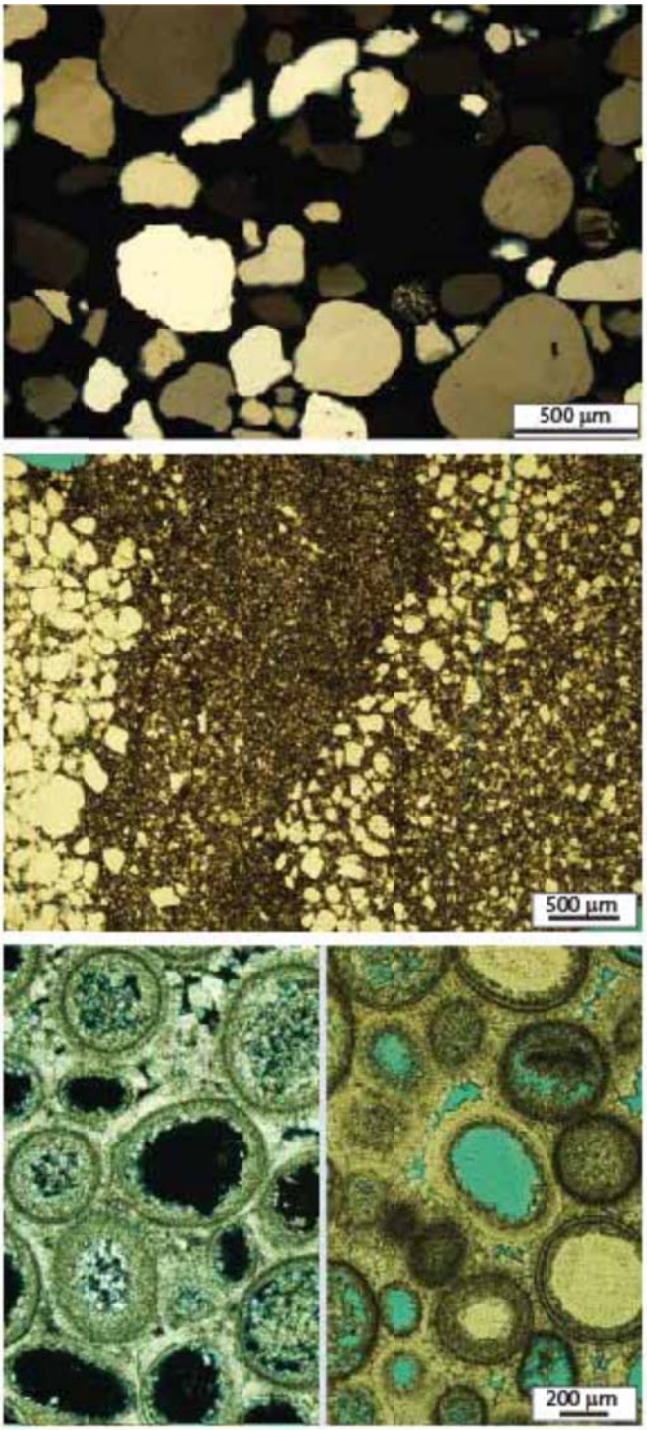


Figure 25: Isopach map of the New Richmond Sandstones.

145 feet toward the southeast in southwestern LaSalle County. Southeastward, it thins rapidly and grades to sandy dolomite and dolomite. The New Richmond Sandstone is fine to medium grained porous and commonly friable sandstone with interlayered finely crystalline dolomite and dolomitized grainstone (Fig. 26).



Fine to medium grained, rounded quartz sandstone under polarized light; Thin section photomicrograph from Vickery Drilling Co., Inc., Mathesius No.1, LaSalle Co. IL; (depth 285-90 ft).

Interlamination of very finely crystalline dolomite and fine grain sandstone under plain light (depth 3,910-3,920 ft).

Blue dye impregnated dolomitized ooid grainstone, under plain and polarized light showing moldic and intercrystalline porosity, and silicified ooid cores (depth 3,930-3,940 ft).

Figure 26: Photomicrographs of the New Richmond Sandstone.

The Shakopee Dolomite unconformably underlies the Upper Ordovician St. Peter Sandstone in northern and central Illinois, but in southern Illinois it underlies the Middle Ordovician Everton Dolomite (Figs. 5 through 7). It is of variable thickness (50-150 feet) in northern Illinois, but thickens southward to over 2500 feet in extreme southern Illinois (Fig. 6a). The Sh akopee Dolomite contains thin layers of quartz sandstone. It is fine to coarsely crystalline commonly dense dolomite with relics of carbonate grains and commonly display bioclast ooid, and peloid grainstone facies in chert noduls (Fig. 27). It is locally fractured and brecciated showing a very high porosity and permeability (Fig. 28). The overlying Everton Dolomite in southern Illinois consists predominantly of limestone showing mudstone to grainstone facies containing bioclasts, peloids and intraclasts (Fig. 29).

ENVIRONMENT OF DEPOSITION

The carbonate units in the Cambro-Ordovician Knox consist mainly of mudstone to grainstone facies containing bioclasts, ooids, intraclasts and peloids; in the dolomitized equivalent, the carbonate grains are preserved in chert nodules or as relicts, recording deposition on a shallow marine carbonate ramp (Ahr, 1998) setting.

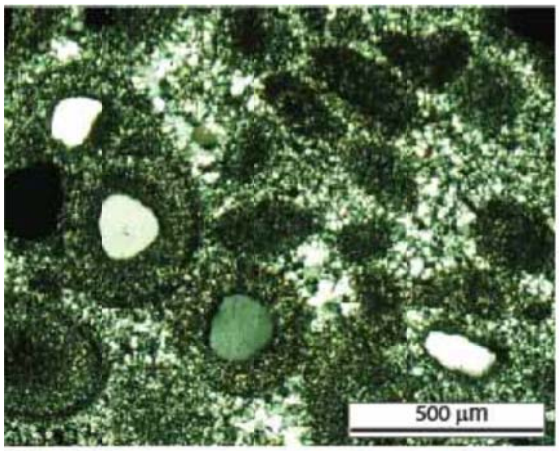
The sandstone units are primarily quartzose and commonly display excellent textural and compositional maturity. Intercalation of dolomite layers with gradational contacts and evidence of shallow marine deposition suggests deposition in a shallow marine tide and wave dominated environment. Some sandstones include intervals with frosted bimodal sand grains showing excellent rounding even in finer grain size, suggesting aeolian to coastal plain deposition in the inner ramp setting during sea level drawdown followed by varying amount of reworking during sea-level rise.

Except for a few localities in western and northern Illinois and in neighboring states (e.g., Palmer 1989; Overstreet et al. 2003), tidal flat deposits are not common and deposition primarily occurred in the open marine, ramp margin shoals and lagoonal settings (Fig. 30). During the Cambro-Ordovician short-term sea-level drawdown, the inner platform areas in the north was exposed but, carbonate deposition continued in the southeastern portion of the Illinois Basin because subsidence was equal to or in excess of base-level fall.

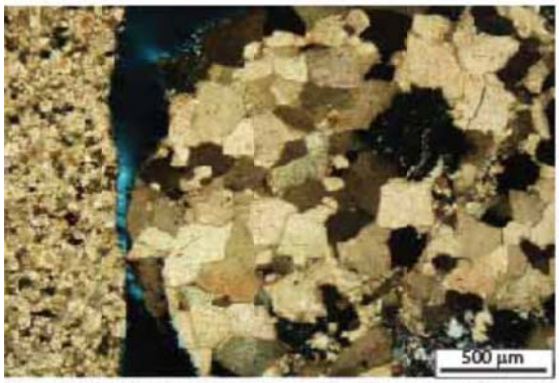
CONCLUSIONS

The results of this study show that the Cambro-Ordovician Knox Group in the Illinois Basin and adjacent Midwestern regions may be an attractive target for CO2 sequestration because these rocks are 1) laterally extensive, 2) consist of some porous and permeable dolomite and sandstone intervals, and 3) contain abundant impermeable shale and carbonate seals.

Porous and permeable vugular or fractured/cavernous dolomite intervals that grade to



Chertified ooid intraclast grainstone under polarized light from Texaco Inc., Cuppy No. 1, Hamilton Co. IL; (depth 8500-05 ft).



Fine to medium crystalline dolomite under polarized light; Thin section photomicrograph from Conoco Inc.Dyhrkopp No. 4-1, Gallatin Co. IL; (depth 7140-50 ft)

Figure 27: Photomicrographs of the Shakopee Dolomite.

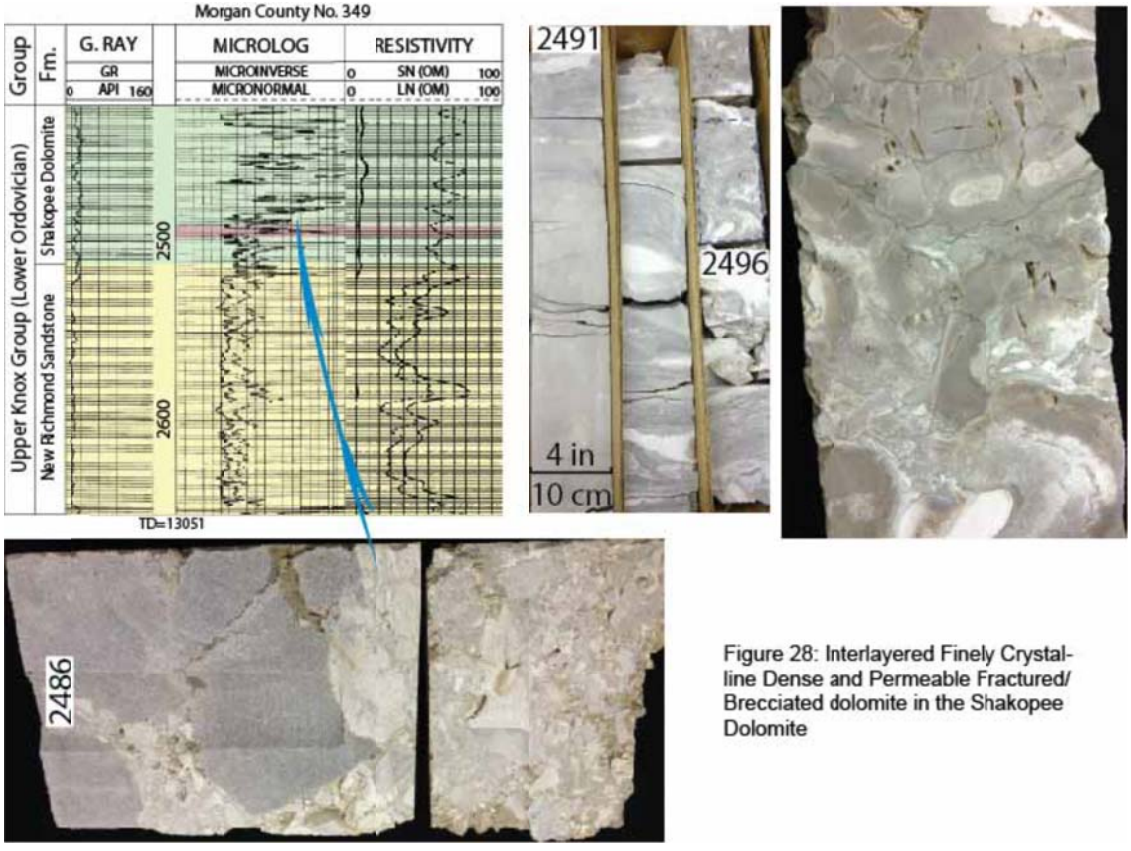
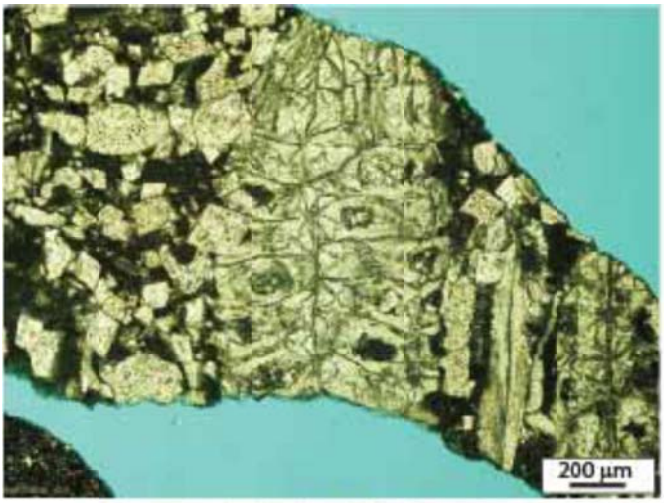
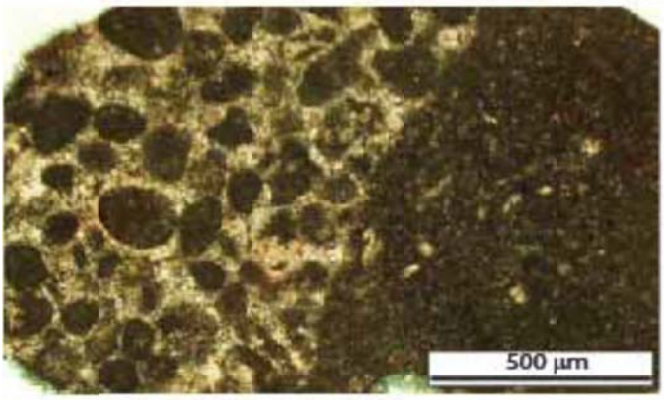


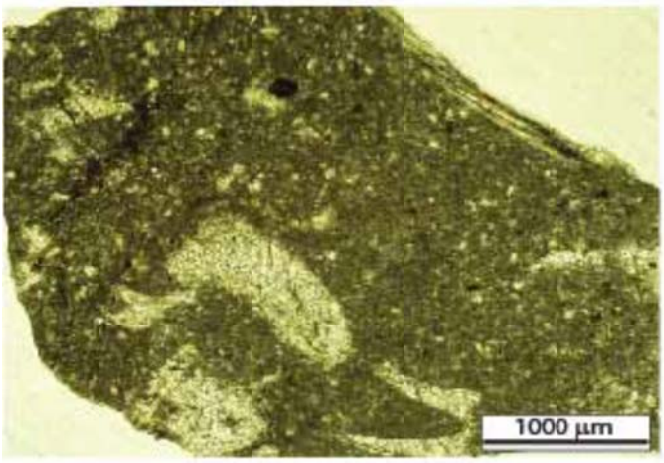
Figure 28: Interlayered Finely Crystalline Dense and Permeable Fractured/ Brecciated dolomite in the Shakopee Dolomite



Fossiliferous lime wackestone with bryozoan and echinoderm fragments under plain light (depth 3,480-3,490 ft.).



Lime mudstone capped by intraclastic grainstone facies under plane light; Thin section photomicrograph from Texaco Inc. Johnson No. 1, Marion Co. IL; (depth 5570-80 ft).



Fossiliferous lime mudstone to wackestone with echinoderm fragments under plane light; from Texaco Inc., Cuppy No. 1, Hamilton Co. IL; (depth 7760-65 ft).

Figure 29: Photomicrographs of the Everton Dolomite.

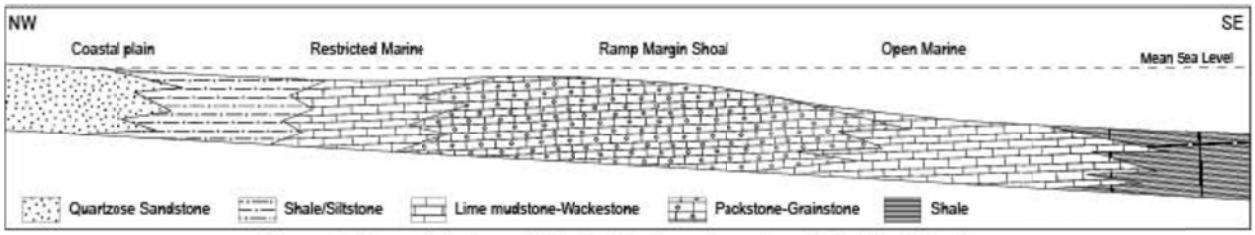


Figure 30: Depositional model during the Knox deposition in the Illinois Basin.

dense fine to coarsely crystalline dolomite are present within the dolomite units. Several hundred barrels of fluid were lost in some of these porous intervals during drilling indicating high permeability. The sandstone intervals are porous and permeable and are texturally and compositionally mature. They commonly contain thin beds of fine to coarsely crystalline dolomite intercalations, indicating deposition in a shallow to marginal marine settings.

The permeable sandstone and dolomite intervals are laterally extensive and could serve as important reservoirs to store natural gas, CO2 or hazardous waste material. The dominant lithology of the Knox and the overlying Prairie du Chien Group is fine to coarsely crystalline dense dolomite. The intercrystalline pore space of the dolomite was lost as a consequence of later stage diagenetic dolomite overgrowth or cementation. The dense dolomite intervals, therefore, could serve as an effective seal for the encompassing porous and permeable sandstone and dolomite intervals.

The results of this study show that the Cambro-Ordovician Knox deposits of Illinois, because of their thickness (over 7000 feet), widespread occurrence, and depth (over 2500 feet) in central and southern deep part of the basin, can provide a significant reservoir for CO2 storage. Furthermore, the porous rocks of the Knox Group can also capture any CO2 that may leak from the underlying Mt. Simon Sandstone, currently a major target reservoir for CCS in the U.S. Midcontinent.

REFERENCES

Ahr, W.M., 1998. Carbonate ramps, 1973-1996: a historical review. In: Wright, V.P., Burchette, T.P. (eds.), Carbonate Ramps. Geological Society of London Special Publication 149, p. 7-14.

Bond, G.D., Nickeson, P.A., Kominz, M.A., 1984. Breakup of a supercontinent between 635 Ma and 555 Ma: New evidence and implications for continental histories. Earth and Planetary Science Letters 70, p. 325-345.

Buschbach, T.C. 1975. Cambrian System. In: Willman, H.B., Atherton, E., Buschbach, T.C., Collinson, C., Frye, J.C., Hopkins, M.E., Lineback, J.A., Simon, J.A. (eds.), Handbook of Illinois Stratigraphy, p. 34-46.

Buschbach, T.C. and Kolata, D.R., 1991. Regional setting of Illinois Basin. In: Leighton, M.W., Kolata, D.R., Olts, D.F., Eidel, J.J. (eds.), Interior Cratonic Basins. AAPG Memoir 51, p. 29-55.

Fritz, R. D., Morgan, W. A., Longacre, S., Derby, J. R., and Sternbach, C. A., 2012. Introduction. In: J. R. Derby, R. D. Fritz, S. A. Longacre, W. A. Morgan, and C. A. Sternbach (eds.), The great American carbonate bank: The geology and economic resources of the Cambrian–Ordovician Sauk megasequence of Laurentia: AAPG Memoir 98, p. 1-3

Kolata, D.R. and Nelson, W.J., 1991. Tectonic history of the Illinois Basin. In: Leighton, M.W., Kolata, D.R., Oltz, D.F., Eidel, J.J. (eds.), Interior Cratonic Basins. AAPG Memoir 51, p. 263-285.

Kolata, D.R. and Nelson, W.J., 2011. Tectonic history. In: Kolata and C. K. Nimz (eds.) Geology of Illinois. Illinois State Geological Survey, p. 77-89.

Kolata, D.R., 2011. Cambrian and Ordovician Systems. In: Kolata and C. K. Nimz (eds.) Geology of Illinois. Illinois State Geological Survey, p. 136-166.

Miller, J. F., Evans, K. R., Kurtz, V. E., and Repetski John. F. 2013. Biostratigraphy and Sequence Stratigraphy of Cambrian and Lowest Ordovician Strata in Missouri. In: Mulvany, P. S. and Thompson, T. L. (eds.), Paleozoic Succession in Missouri, Part 1-Cambrian System: Missouri Department of Natural Resources, Missouri Geological Survey, Report of Investigations 70, p. 13-24.

Overstreet, R. B., Oboh-Ikuenobe, F. E., and Gregg, J. M., 2003. Sequence stratigraphy and depositional facies of Lower Ordovician cyclic carbonate rocks, southern Missouri, USA. J. of Sedimentary Research 73, p. 421-233.

Palmer, A. R., 1981, Subdivision of the Sauk sequence. In: M. E. Taylor, ed., Short papers for the 2nd International Symposium on the Cambrian System: U.S. Geological Survey Open File Report 81-743, p. 160–162.

Palmer, J. R., 1989. Late Upper Cambrian shelf depositional facies and history, southern Missouri. Field guide to the Upper Cambrian of southern Misouri; stratigraphy, sedimentology, and economic geology, p. 1-24.

Palmer, J., T. L. Thompson, C. Seeger, J. F. Miller, and J. M. Gregg, 2012. The Sauk megasequence from the Reelfoot rift to southwestern Missouri. In: J. R. Derby, R. D. Fritz, S. A. Longacre, W. A. Morgan, and C. A. Sternbach (eds.), The great American carbonate bank: The geology and economic resources of the Cambrian–Ordovician Sauk megasequence of Laurentia: AAPG Memoir 98, p. 1013–1030.

Piper, J.D.A., 2004. Discussion on “The making and unmaking of a supercontinent: Rodinia revisited” by J.G. Meert and T.H. Torsvik, Tectonophysics, 375 (2003) 261–288. Tectonophysics 383, p. 91-97.

Sloss, L.L., 1963. Sequences in the cratonic interior of North America. GSA Bulletin 74, p. 93-114.

Willman, H.B. and Buschbach, T.C., 1975. Ordovician System. In: Willman, H.B., Atherton, E., Buschbach, T.C., Collinson, C., Frye, J.C., Hopkins, M.E., Lineback, J.A., Simon, J.A. (eds.), Handbook of Illinois Stratigraphy, p. 47-87.

APPENDIX: HIGHER RESOLUTION FIGURES 5 THROUGH 7

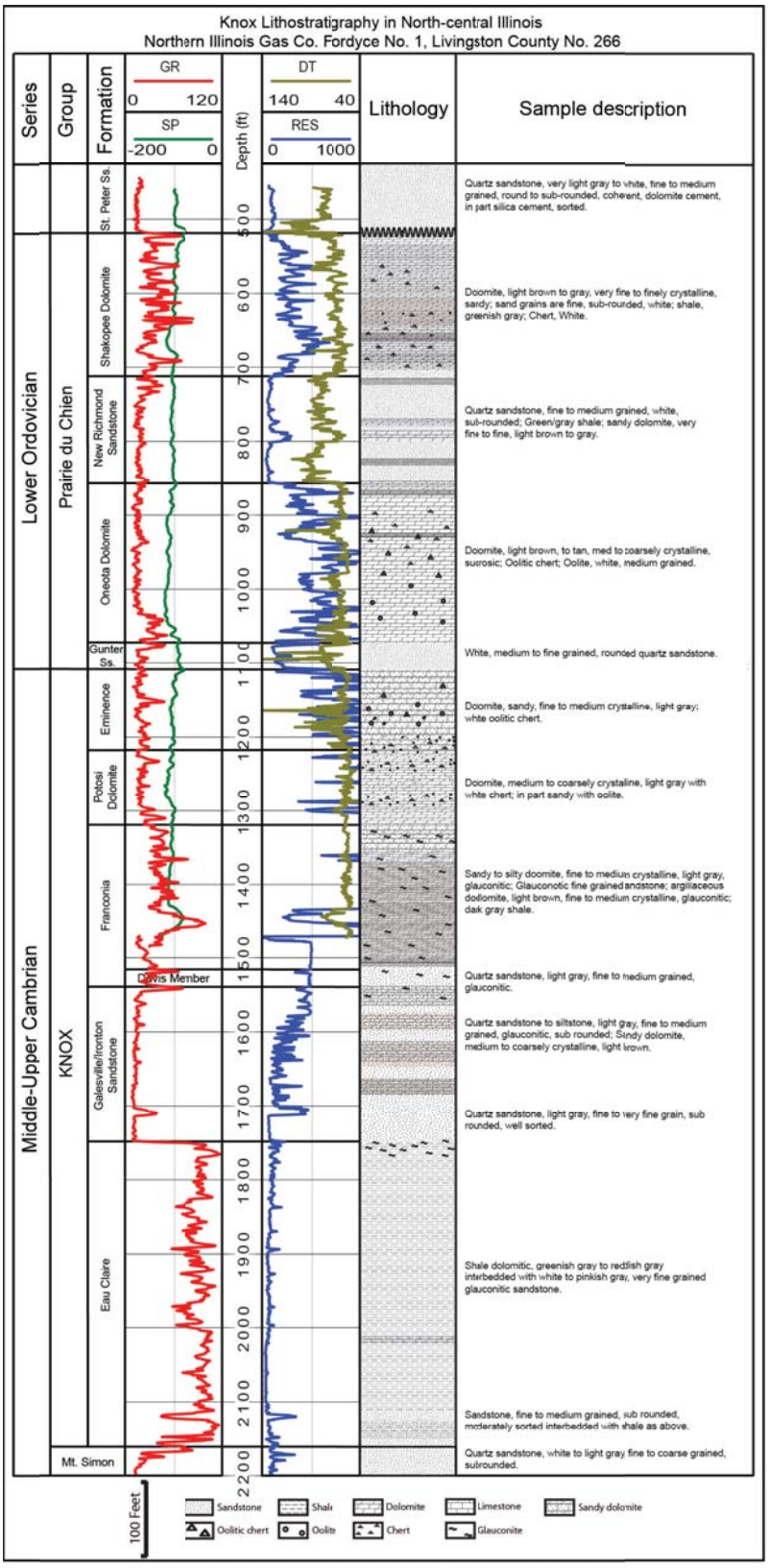


Figure 5: Type log of the Cambro-Ordovician Knox deposits in northern Illinois.

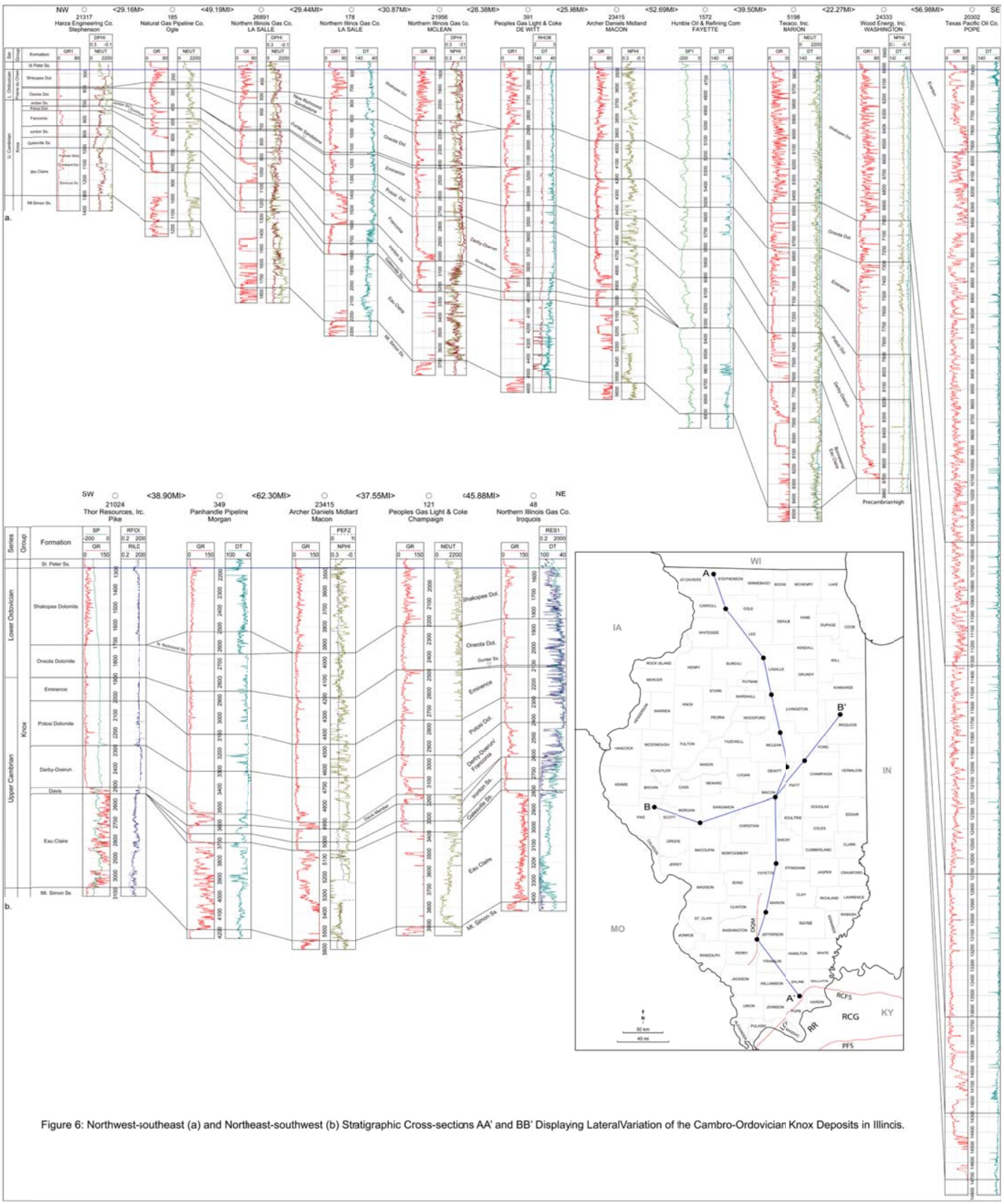


Figure 6: Northwest-southeast (a) and Northeast-southwest (b) Stratigraphic Cross-sections AA' and BB' Displaying LateralVariation of the Cambro-Ordovician Knox Deposits in Illincis.

Figure 6

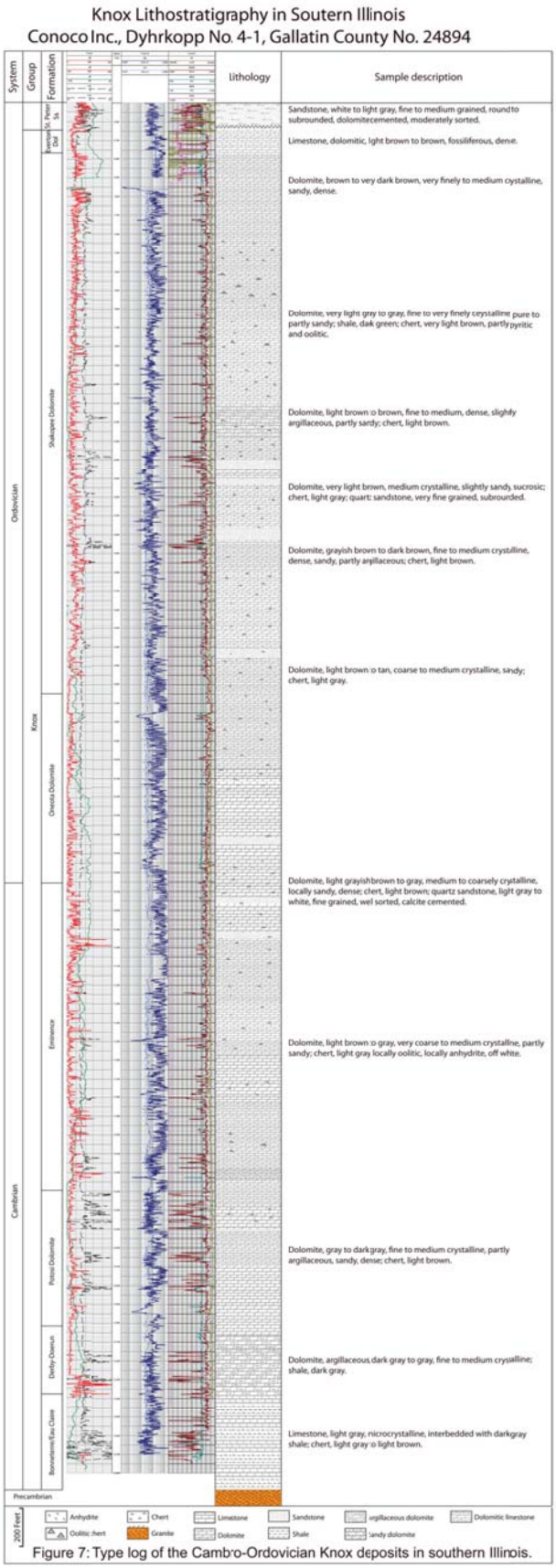


Figure 7: Type log of the Cambro-Ordovician Knox deposits in southern Illinois.

ACKNOWLEDGMENTS

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