PSTOC Estimation of the New Albany Shale Group Shale-Using ΔlogR Evaluation Technique, Central and Southern Illinois*

Mansour Khosravi Rokrok¹ and Donna C. Willette²

Search and Discovery Article #51455 (2018)**
Posted January 15, 2018

*Adapted from poster presentation given at AAPG 2017 Eastern Section 46th Annual Meeting, Morgantown, West Virginia, September 24-27, 2017
**Datapages © 2018 Serial rights given by author. For all other rights contact author directly.
Winner of the best paper in the Energy Mineral Division at the AAPG 2017 Eastern Section 46th Annual Meeting, Morgantown, West Virginia, September 24-27, 2017

¹Prairie Research Institute, University of Illinois at Urbana-Champaign, Illinois State Geological Survey, Champaign, IL (<u>mansourk@illinois.edu</u>)
²Prairie Research Institute, University of Illinois at Urbana-Champaign, Illinois State Geological Survey, Champaign, IL

Abstract

Accurate quantification of the total organic carbon (TOC) content of source rocks is a crucial parameter in the evaluation of organic-rich unconventional reservoirs. Organofacies in source intervals can vary dramatically in a lateral and vertical sense. Petrophysical data provide an avenue to map these changes without relying on expensive lab analyses. In mature basins, the vast majority of petrophysical data is determined from older logging suites. The ΔlogR technique developed by Passey et al., 1990, allows the use of this data in mapping reliable TOC estimates. For this study, eight wells were selected to compare core-derived TOC data with those computed from the $\Delta logR$ technique in southern Illinois. Shale intervals within the New Albany Shale Group (Devonian to lower Mississippian) and Maquoketa (Ordovician) were analyzed. The ΔlogR technique relies on the density difference of organic carbon (0.9-1.05 g/cc) and mineral matrix (2.65-2.71 g/cc) that porosity logs (sonic, density, or neutron) measure. This requires the overlaying of a sonic, density, or neutron curve in arithmetic scale on a deep resistivity curve on logarithmic scale. Baseline is determined in a shale interval with low organic content. Once baseline is established, the separation between the porosity and resistivity curves can be calibrated over intervals with higher organic content. This calibration requires an estimation of the level of organic metamorphism (LOM) or how far density or transit time deviates from that of barren rock at the same state of compaction. Level of organic metamorphism (LOM) was calculated by using cross plots of measured TOCs from analyses vs ΔlogR, and by vitrinite reflectance (Ro) data determined from nearby wells. Results computed from the $\Delta log R$ method indicate a range of values between 2 to 9% TOC for the New Albany Shale Group and 0.5 to 3.2% TOC for the Maquoketa Shale. More importantly, the TOC values computed from the $\triangle \log R$ method compare reasonably well with values determined from sample analyses. The $\triangle \log R$ technique for these intervals gives satisfactory results with a range of 0.8 to 1.36% TOC standard deviation. Problems arise in correlating laboratory and log data when there are depth matching errors between logs and core and digitized petrophysical curves are of poor quality. In summary, $\Delta logR$ technique can provide reasonable TOC estimate for shale intervals within the Illinois Basin.

References Cited

Atherton, E., C. Collinson, and J.A. Lineback, 1975, New Albany Shale Group, *in* H.B. Willman. E. Atherton. T.C. Buschbach. C. Collinson. J.C. Frye. M.E. Hopkins, F.A. Lineback, and J.A. Simon (eds.), Handbook of Illinois Stratigraphy: Illinois State Geological Survey Bulletin 95, p. 120.

Cluff, R.M., M.L. Reinbold, and J.A. Lineback, 1981, The New Albany Shale Group of Illinois: Illinois State Geological Survey Circular 518, 83 p.

Collinson, C., and E. Atherton, 1975, Devonian System: Handbook of Illinois Stratigraphy, Illinois State Geological Survey Bulletin 95, p. 104-123.

Crain, E.R., 2013, Welcome to Crain's Petrophysical Handbook: Online Shareware Petrophysics Training and Reference Manual. https://www.spec2000.net/. Website accessed December 2017.

Lazar, O.R., 2007, Redefinition of the New Albany Shale of the Illinois Basin: An Integrated Stratigraphic, Sedimentologic, and Geochemical Study: Ph.D. Thesis, University of Indiana, Bloomington, IN, 362 p.

Mastalerz, M., A. Drobniak, J. Rupp, B. Nuttall, and J. Crockett, 2014, Evaluation of Geological Characteristics of the New Albany Shale as a Potential Liquids-from-Shale play in the Illinois Basin: 2014 Eastern Unconventional Oil and Gas Symposium, November 5-7, 2014, Lexington, Kentucky.

North, W.G., 1969, The Middle Devonian Strata of Southern Illinois: ISGS Publications, Circular 441, 49 p.

Passey, Q.R., K.M. Bohacs, W.L. Esch, and S. Sinha, 2010, From Oil Prone Source Rock to Gas Producing Shale Reservoir – Geologic and Petrophysical Characterization of Unconventional Shale-Gas Reservoirs: CPS/SPE International Conference, Beijing, China, June 8-10, 2010, SPE 131350, 29 p.

Passey, Q.R., S. Creaney, J.B. Kulla, F.J. Moretti, and J.D. Stroud, 1990, A Practical Model for Organic Richness from Porosity and Resistivity Logs: American Association of Petroleum Bulletin, v. 74/12, p. 1777-1794.

Strapoc, D., M. Mastalerz, A. Schimmelmann, A. Drobniak, and N.R. Hasenmueller, 2010, Geochemical Constraints on the Origin and Volume of Gas in the New Albany Shale (Devonian–Mississippian), Eastern Illinois Basin: American Association of Petroleum Geologists Bulletin, v. 94, p. 1713-1740.

Whiting, L.L., and D.L. Stevenson, 1965, The Sangamon Arch: Illinois State Geological Survey, Circular 383, 20 p.

Workman, L. E., and T. Gillette, 1956, Subsurface Stratigraphy of the Kinderhook Series in Illinois: Illinois State Geological Survey, Report of Investigations 189, 46 p.



TOC Estimation of the New Albany Shale Group Shale-Using AlogR Evaluation Technique, Central and Southern Illinois



Introduction

Accurate quantification of the total organic carbon (TOC) content of source rocks is a crucial parameter in the evaluation of organic-rich unconventional reservoirs. Organofacies in source intervals can vary dramatically in a lateral and vertical sense. Petrophysical data provide an avenue to map these changes without relying exclusively on expensive lab analyses. Even in basins with significant well penetrations, the amount of geochemical data may be relatively sparse. As is the case of the Illinois Basin, the vast majority of petrophysical data in mature basins is determined from older (pre-2000) logging suites. The ΔlogR technique developed by Passey, et al., 1990, allows the use of this data in mapping reliable TOC estimates.

The ΔlogR technique relies on the density difference of organic carbon (0.9-1.05ρο) and mineral matrix (2.65-2.71ρm) that porosity logs (sonic, density, or neutron) measure. This requires the overlaying of a sonic, density, or neutron curve in arithmetic scale on a deep resistivity curve on logarithmic scale. Baseline is determined in a shale interval with low organic content. Once baseline is established, the separation between the porosity and resistivity curves can be calibrated over intervals with higher organic content. This calibration requires an estimation of the level of organic metamorphism (LOM) or how far density or transit time deviates from that of barren rock at the same state of compaction. Level of organic metamorphism (LOM) was calculated by using cross plots of measured TOC from analyses versus TOC measured by ΔlogR, and also by vitrinite reflectance (Ro) data determined from nearby wells. The overall goal of this study is to expand in more detail the variation in TOC present in the New Albany Shale. TOC fluctuates in a vertical and lateral sense as organofacies change within the New Albany Shale. Determining average TOC from continuous petrophysical data is a more reliable methodology than using extremely limited sample points from cuttings and core analyses.

The objectives of this study are: (1) to compute TOC data of New Albany Shale Group by using ΔlogR technique; (2) to plot TOC data vs deep resistivity data and find a proper equation between those data; (3) to compare synthetic TOC data with core-derived (geochemical analyses) TOC in six selected wells; (4) to divide the New Albany Shale Group into several zones based on its lithology and petrophysical log characteristics and compute TOC data in more than 100 wells in central and southern Illinois; (5) to prepare 2-D cross sections and TOC and thickness maps for each zone to identify TOC and thickness trends.

Stratigraphy

The New Albany Shale Group (Middle Devonian-Kinderhookian) is an extremely rich organic shale interval that extends throughout Illinois, Indiana, and western Kentucky. It consists of continuous and discontinuous brownish black, gray, and greenish-gray shales (Collinson and Atherton, 1975; Cluff et al., 1981). The New Albany Shale Group is conformably overlain by the Chouteau Limestone. In southeastern Illinois, the Chouteau Limestone is overlain by the Springville Shale (Valmeyrean) where the Chouteau has thinned and pinched out (Atherton et al., 1975). In southern and eastern Illinois, the New Albany Shale overlies the Lingle and Alto Formation (North, 1969). In much of northwestern and western Illinois, the New Albany Shale Group uncomfortably overlies the Cedar Valley Limestone, and close to Sangamon Arch onlaps the Silurian strata (Whiting and Stevenson, 1965). The New Albany Shale Group was deposited in a shelf-slope marine environment during times of fluctuating sea levels and clastic input. This resulted in oscillating degrees of anoxia within the basin (Cluff et al., 1981). Recent work indicates that there are least four depositional sequences bounded by laterally extensive erosion surfaces with internal parasequence sets (Lazar, 2007). The New Albany Shale Group has a maximum thickness of 460 feet (140 meter) in southeastern Illinois consisting of brownish black laminated shale. Westward, it abruptly thins to less than 50 feet (15 meter) due to the extension of the Ozark uplift (Workman and Gillette, 1956).

The New Albany Shale Group is subdivided into nine formations based upon lithostratigraphy and historical convention in Illinois: 1) Hannibal Shale; 2) Horton Creek Shale; 3) Louisiana Limestone; 4) Saverton Shale; 5) Grassy Creek Shale; 6 and 7) Selmier and Sweetland Creek Shales; 8) Sylamor Sandstone; 9) Blocher Shale. However, these formations grade laterally and may be eroded in some localities. Tectonic activities, paleotopography, fluctuations in sea level, and change in accommodation space are the primary controls on deposition of each unit (Lazar, 2007).

In this study, six horizons have been delineated along with correlative zones based on petrophysical logs and lithologies throughout the Illinois. The Grassy Creek Shale has been divided into three zones, which may represent different sequence system tracts and fluctuations in sea level.

Figure 1. North-South expanded cross section showing the New Albany Shale Group lateral and vertical variation in thickness. The New Albany Shale Group has been subdivided into six units: Hannibal-Saverton Shale; Grassy Creek Shale (GK1); Grassy Creek 2 (GK2); Grassy Creek 3 (GK3); Selmier Shale; Blocher Shale. The horizon and unit determinations were based on the petrophysical log characteristics, the depth of formations, lithology, and trace key geophysical horizons and beds. The highlighted unit and horizons can be traced continuously though N-S direction. The location of selected wells are marked on the map. Datum is the top of the Grassy Creek Shale. Abbreviations: GR, gamma ray; RILD and ILD, induction log deep resistivity; RHOB, density; DT, sonic.

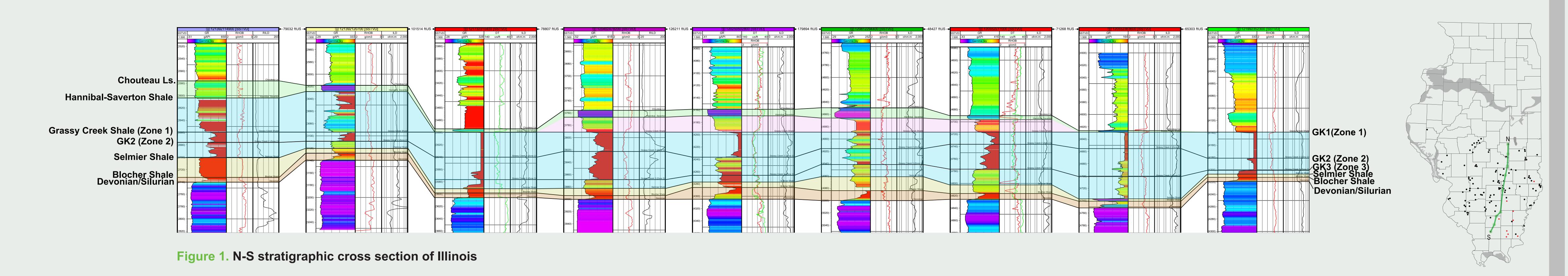
Figure 2. West-East expanded cross section showing the New Albany Shale Group lateral and vertical variation in thickness in Illinois. The lower part of the New Albany Shale Group thins westward near the Sangamon Arch due to tectonic activities, paleotopography and low accommodation space. The discontinuous nature of the New Albany Shale in lateral direction make consistent and exact correlation difficult. The location of selected wells are marked on the right map. Datum is the top of the Grassy Creek Shale. Abbreviations: GR, gamma ray; RILD and ILD, induction log deep resistivity; RHOB, density; DT, sonic.

Figure 3. The expanded cross section of six selected wells with core-derived TOC data. The ΔlogR, Wt % TOC values has been computed by Passey, et al., 1990 method. The TOC values have been also calculated by generated formula, using deep induction resistivity logs. The datum is the top of the Grassy Creek Shale. Results computed from the ΔlogR method and generated formula indicate a range of values between 2.0 to 9.0% TOC for the New Albany Shale Group. More importantly, the TOC values computed through these three methods compare reasonably well with values determined from geochemical sample analyses. The computed values with LOM obtained from core-derived samples and generated formula show less standard deviation in comparison to those computed from vitrinite reflectance (Ro).

The assessment of the New Albany Shale Group horizon and zones indicate that the uppermost Grassy Creek Shale and Blocher Shale intervals contain elevated amounts of organic matter (6 to 11%). The Hannibal-Saverton Shale, the lower part of the Grassy Creek Shale and the Selmier Shale tend to contain lower amounts of organic matter which range from 1.0 to 3.0%.

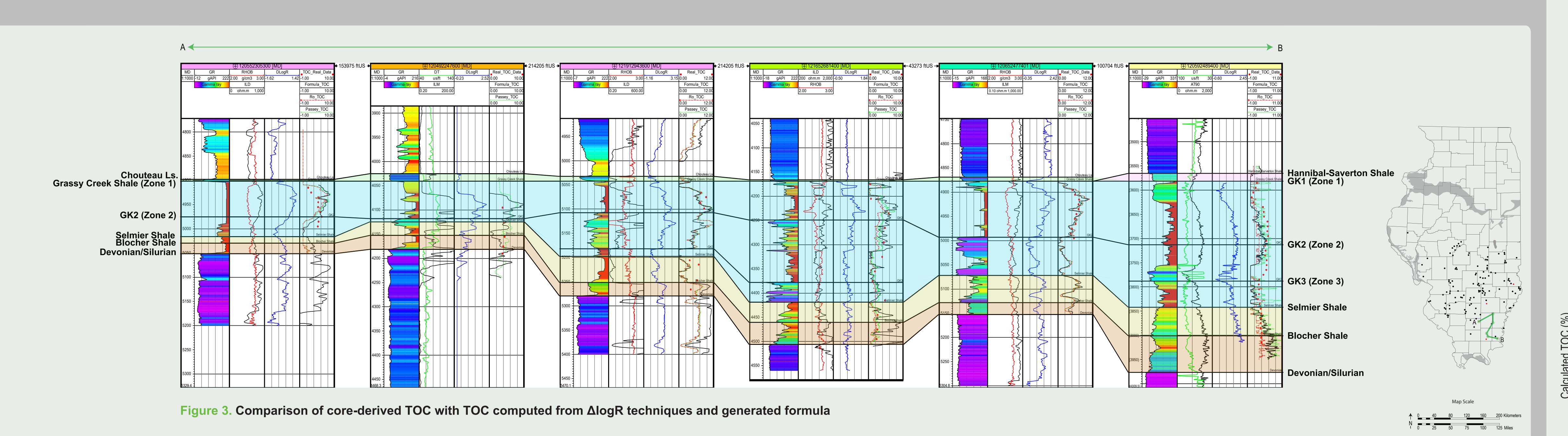
Mansour Khosravi and Donna C. Willette

Prairie Research Institute, University of Illinois at Urbana-Champaign, Illinois State Geological Survey, 615 East Peabody Drive, Champaign, IL 61820



Chouteau Ls.
Gri (Zone 1)
Grassy Creek Shale (Zone 1)
GK2 (Zone 2)
GK2 (Zone 3)
Sodinic Shale
Devontion/Siturian

Figure 1. W-E stratigraphic cross section of Illinois



Results

In this study, the total organic carbon (TOC) of six wells were calculated using Passey et al., 1990 equations and directly compared to core-derived TOC to determine the accuracy and reliability of the petrophysical log-derived measured TOC values.

Calculation of $\Delta logR$ is the first step needed to determine the TOC content of each interval. The porosity (e.g. sonic and density logs) and resistivity curves were overlaid on a shale interval with minimal organic content. This served as a baseline from which curve deviation indicated measurable TOC. The separation distance between two curves (sonic vs resistivity; density vs resistivity; neutron vs resistivity) was measured as $\Delta logR$. Three Passey's equations were utilized to calculate the $\Delta logR$ summarized below (equations 1-3).

$$\Delta LogR = Log 10 \left(\frac{R}{R_{BL}}\right) + 0.02 (\Delta t - \Delta t_{BL}) \quad (1)$$

$$\Delta LogR = Log 10 \left(\frac{R}{R_{BL}}\right) + 4.0 (\phi N - \phi N_{BL}) \quad (2)$$

$$\Delta LogR = Log 10 \left(\frac{R}{R_{BL}}\right) - 2.5 (\rho b - \rho b_{BL}) \quad (3)$$

$$Wt\% TOC = \Delta LogR * 10^{2.297 - 0.1688*LOM} \quad (4)$$

Where:

R= resistivity reading of formation (deep resistivity)

 R_{BL} = resistivity of a shale interval when no TOC present Δt = interval transit time of formation Δt_{BL} = interval travel time of a shale interval when no TOC present

φN= neutron porosity reading of formation
φ_N =neutron porosity of a shale interval when no TOC present

ρb= bulk density reading of formation

 $\rho_{\rm pl}$ = the density of a shale interval when no TOC present

Level of organic metamorphism (LOM) has been obtained from two sources: 1) from the slope of Δ LogR and core-derived TOC values (Fig. 4); 2) from vitrinite reflectance data of Illinois counties. The obtained LOMs were used in equation 4 to compute weight % TOCs. The Ro (vitrinite reflectance) data was used in Δ LogR vs TOC graph (Fig.4) to estimate LOM and compute the weight% TOC.

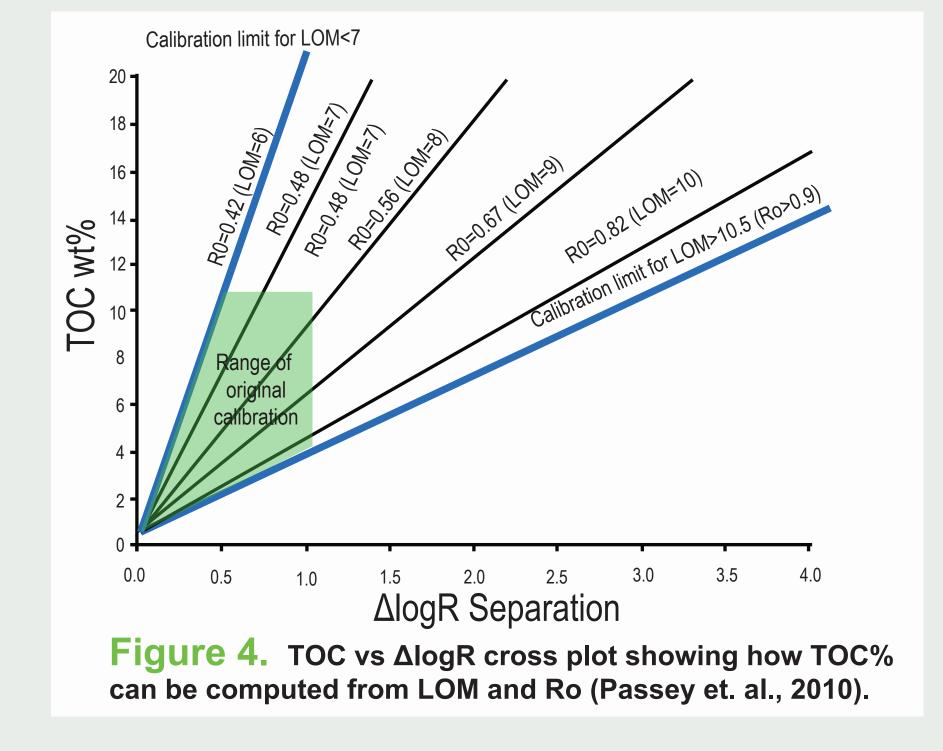
The deep resistivity values were plotted against calculated TOC values from ΔlogR technique. The result shows that there is a logarithmic relationship between those data (Fig. 5). In all cases, the correlation coefficient (R²) of deep resistivity and TOC data is over 0.8 or 80%. The high correlation coefficient between those data led us to determine the following formula and estimate TOC content of shale intervals within the New Albany Shale Group. This correlation implies two things: 1) the organic matter composition and intrinsic density are remarkably consistent in the study area and 2) the ability to use only the deep resistivity curve (ILD) to calculate TOC means older logging suites can still be utilized. This will provide much greater detail of the range and areal distribution of TOC throughout the basin.

Wt %TOC=1.5059In(ILD)-2.0423

Where: ILD= induction deep resistivity

induction deep resistivity

The assessment of the New Albany Shale Group horizon and zones indicate that the uppermost Grassy Creek Shale and Blocher Shale intervals contain elevated amounts of organic matter while the Hannibal-Saverton Shale, the lower part of the Grassy Creek Shale and the Selmier Shale, by comparison, contain significantly lower amounts of total organic carbon.



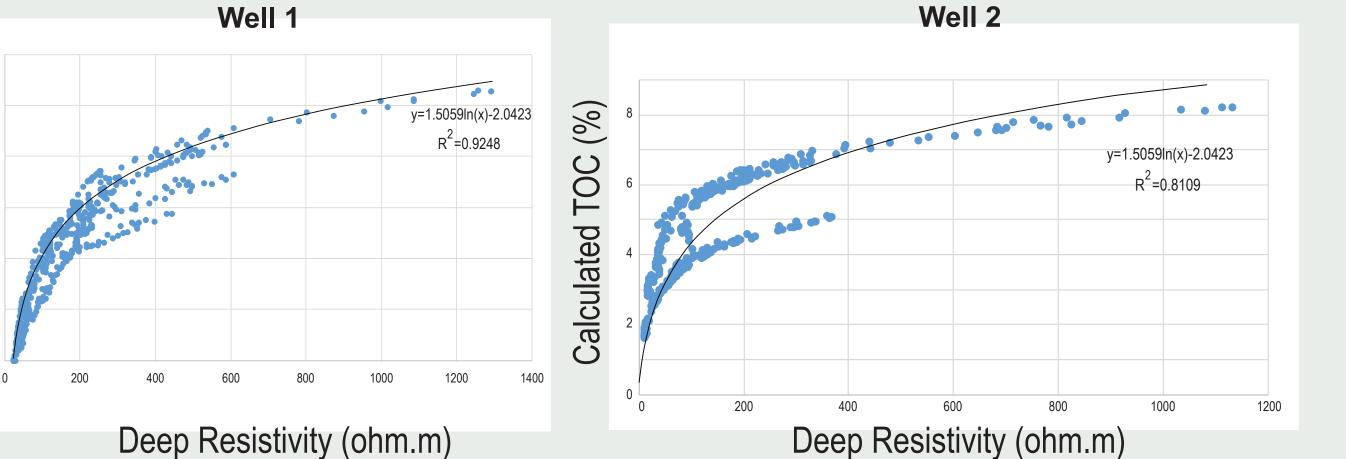


Figure 5. The deep resistivity vs computed TOCs showing a logarithmic relation with correlation coefficient (R²) over 0.8 in two different wells.



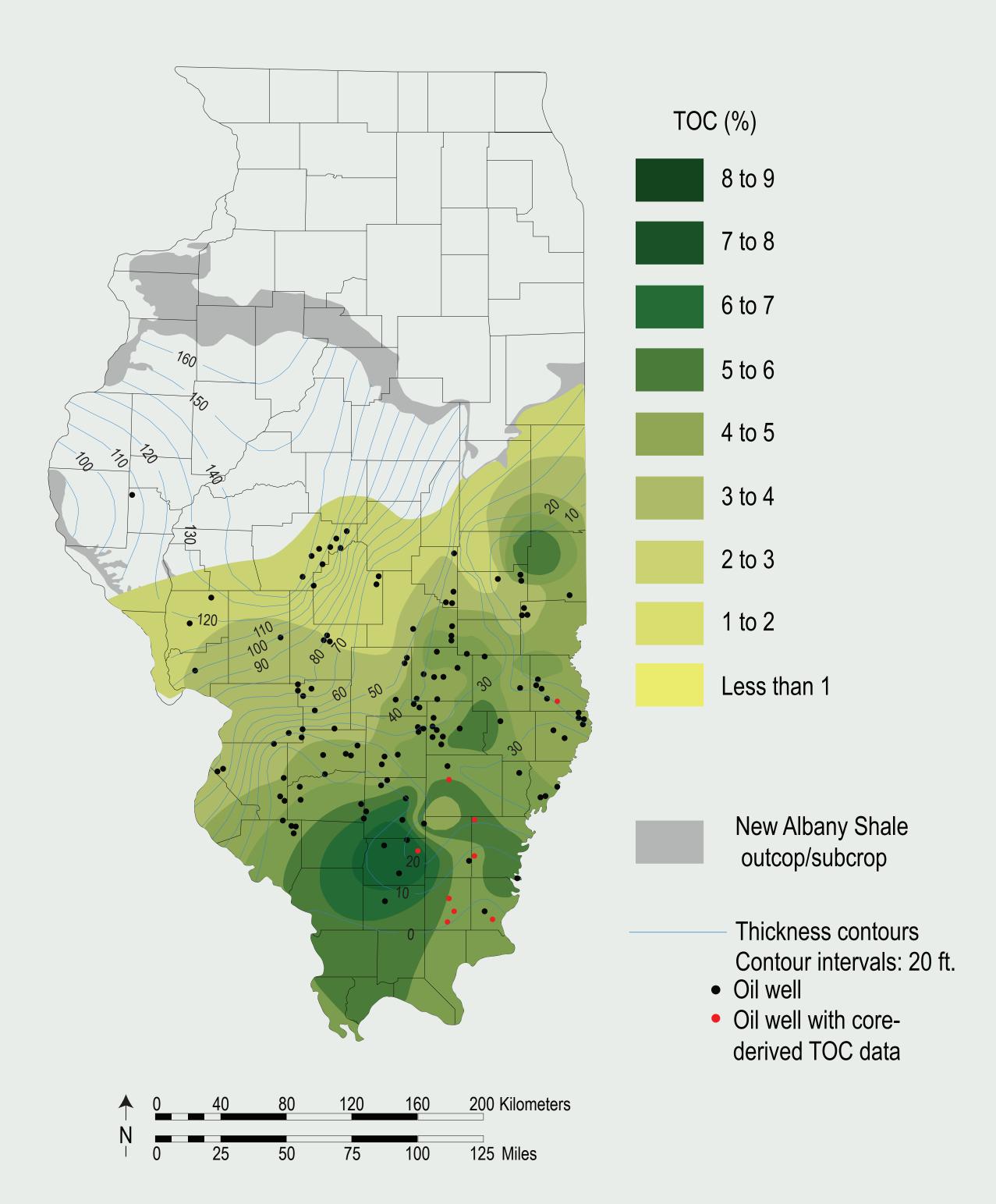


Figure 6. TOC and thickness map of Hannibal-Saverton Formations. Thickness contour intervals are 10 feet (3 meter). TOC intervals are 1.0%. The maximum thickness of the formation occurs in northwestern Illinois. The shale intervals thins and pinches out toward south and southeastern Illinois. The TOC values decrease toward west and north in Illinois.

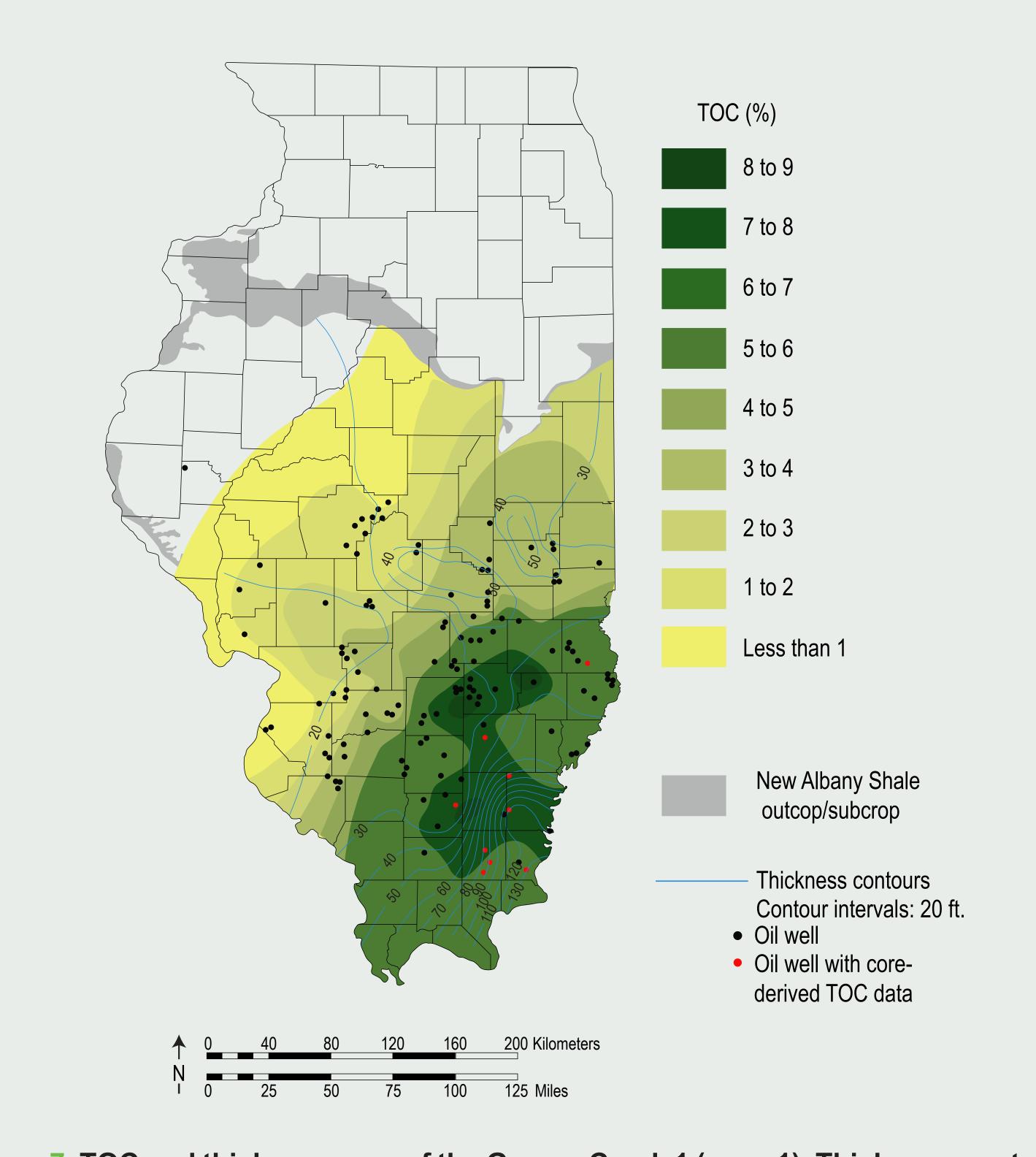


Figure 7. TOC and thickness map of the Grassy Creek 1 (zone 1). Thickness contour intervals are 10 feet (3 meter). TOC intervals are 1.0%. The maximum thickness of the formation occurs in southern Illinois. The shale intervals thins and pinch out toward south and southwestern Illinois. The Grassy Greek 1 (zone 1) has the largest areal extent of high TOC values for all the New Albany Shale formation and zones.

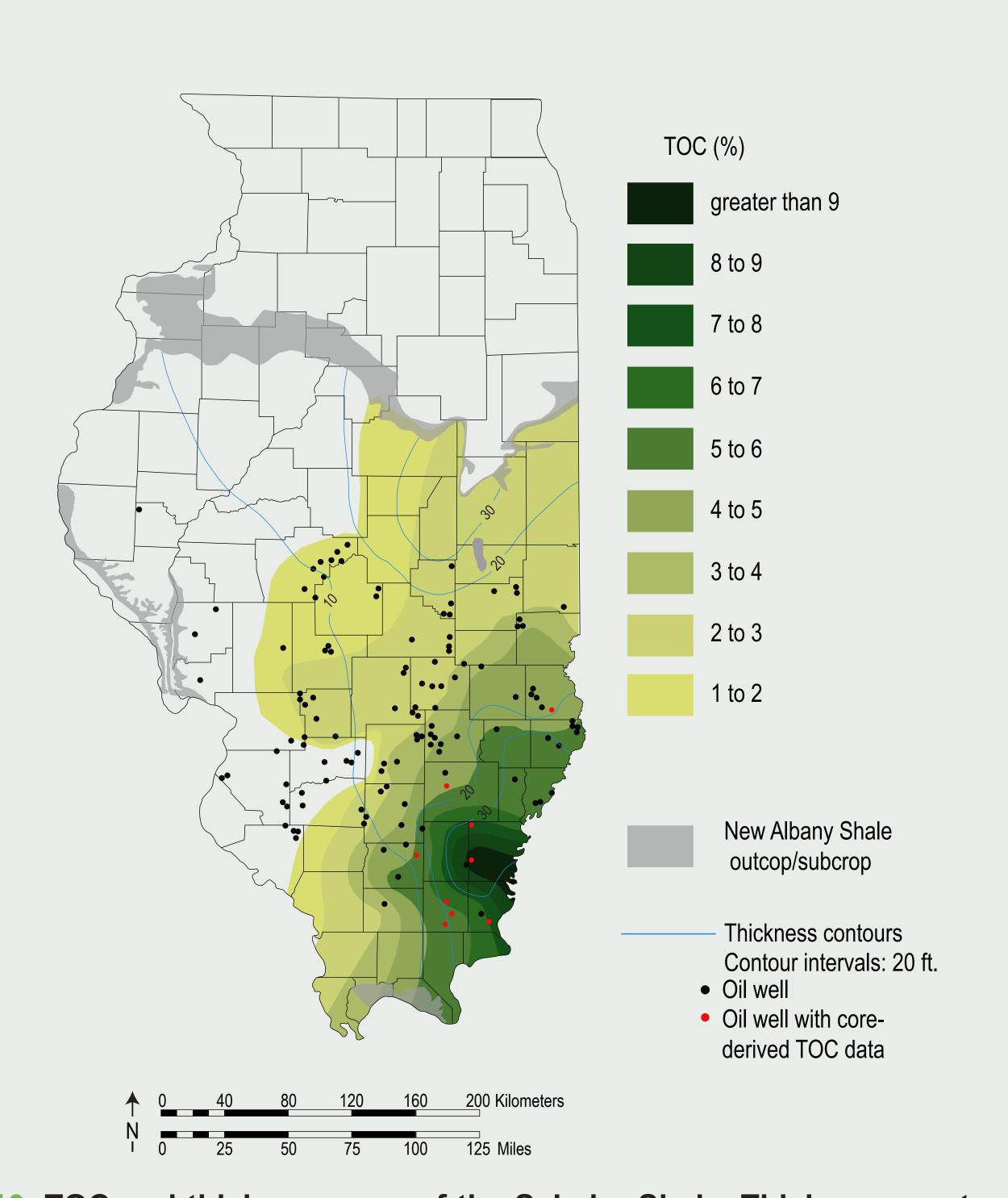


Figure 10. TOC and thickness map of the Selmier Shale. Thickness contour intervals are 10 feet (3 meter). TOC intervals are 1.0%. The shale interval gradually thins and pinches out westward. The TOC values decrease toward west and north in Illinois.

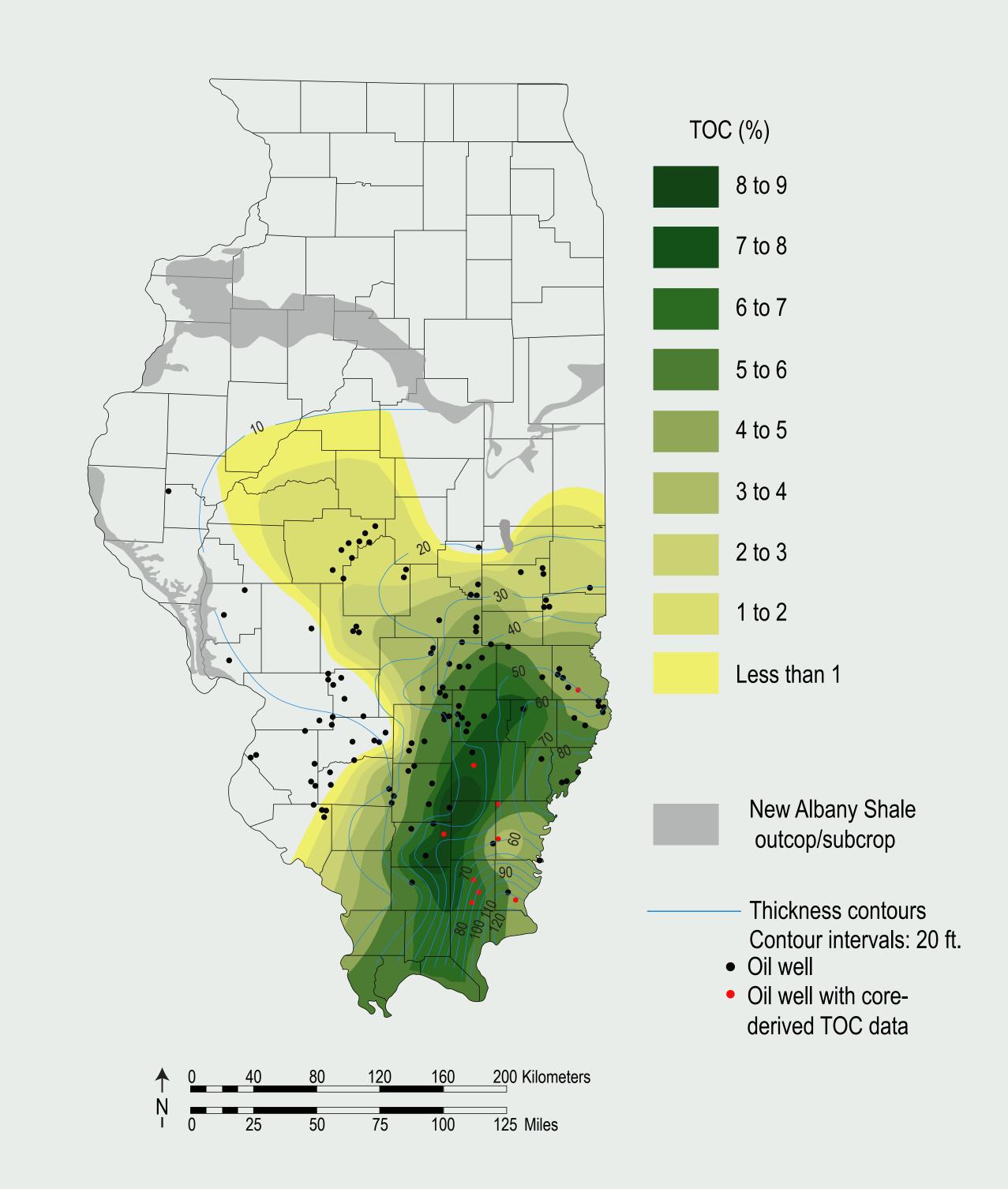
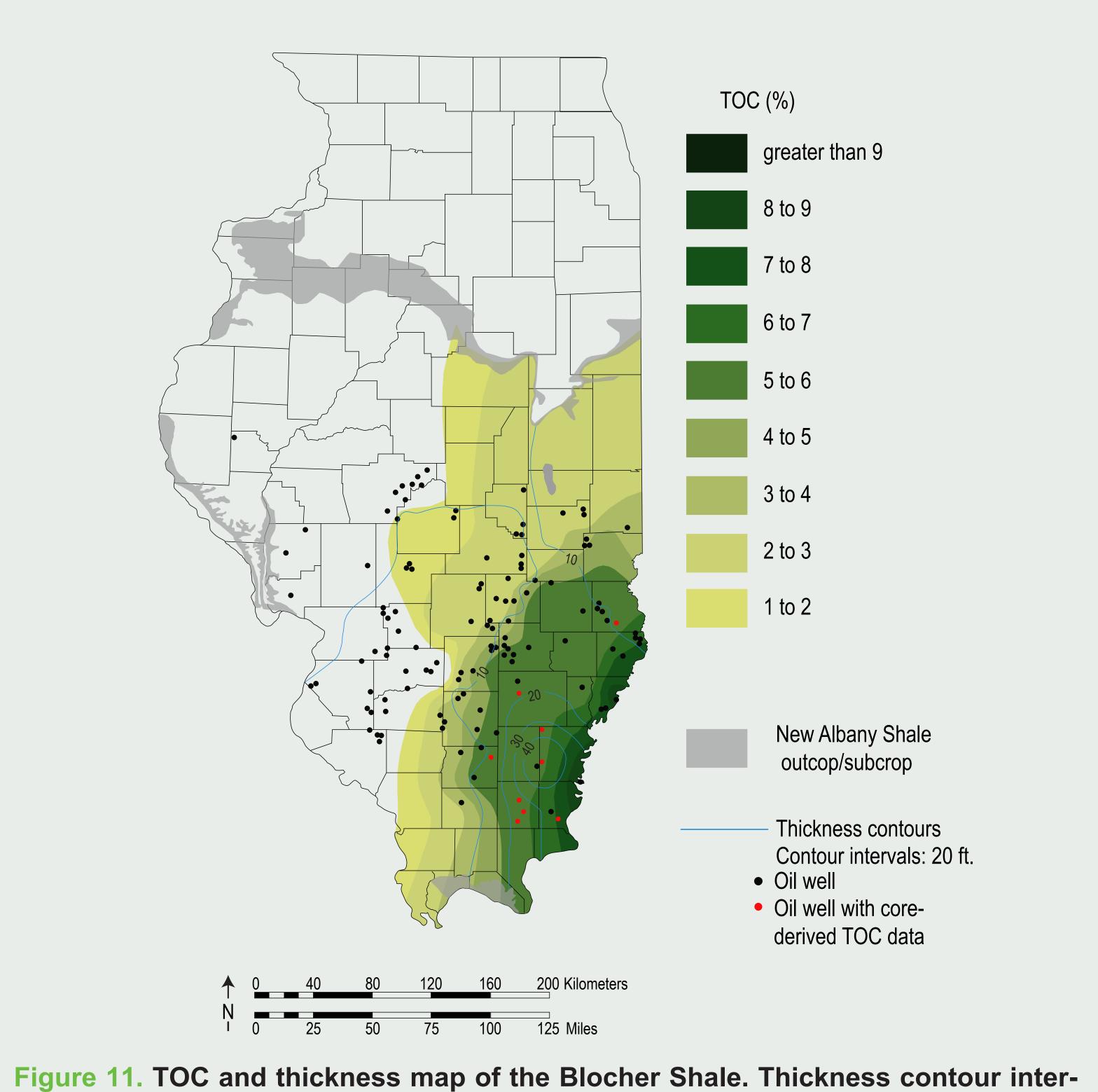


Figure 8. TOC and thickness map of the Grassy Creek 2 (zone 2). Thickness contour intervals are 10 feet (3 meter). TOC intervals are 1.0%. The maximum thickness of the formation occurs in southeastern Illinois. The shale intervals laterally pinch out westward. The maximum 8 to 9 percent total organic carbon content was determined from petrophysical data in southern Illinois.



vals are 10 feet (3 meter). TOC intervals are 1.0%. The thickness map of the Blocher Shale indicates that it is restricted to southeastern and eastern parts of the state. The TOC map indicates that the Blocher Shale consists of elevated TOC values (greater than 9.0%) in southeastern Illinois.



TOC and thickness trends

The petrophysical well logs from over 100 well were utilized to pick the formation tops, determine correlatable zones, and compute the TOC data. From correlations determined from the cross-sections, the thickness and TOC maps of each formation/zone were prepared to assess the TOC and thickness trends. The petrophysical log data along with thickness and TOC map assessment indicate that:

Across much of Illinois, the maximum thickness of the Hannibal-Saverton formations occurs in northwestern Illinois with 160 feet (48 meter) thickness (Figure 6). The shale intervals thins and pinches out toward south and southeastern Illinois. In most areas in the state, the organic content of the Hannibal-Saverton Formation is reduced (compared to other intervals within the New Albany Shale), generally less than 3.0 percent. However, there are some areas with over 7.0 percent TOC in southern Illinois (Figure 6).

The Grassy Creek has the highest gamma-ray and resistivity values among all formations of the New Albany Shale (Figure 1-3). In this study, the Grassy Creek Shale has been subdivide into three zone to separate the high and low TOC intervals. The criteria for the Grassy Creek Shale zonation was based upon petrophysical response and lithology changes.

The Grassy Creek 1 (zone 1), the uppermost portion of the formation has the maximum thickness of about 130 feet (40 m) in southern Illinois (Figure 7). The shale interval thins to less than 20 feet (6 meter) toward the north and west, where it is very difficult to distinguish from the boundary from underlying formations. The Grassy Creek 1 has the highest total organic carbon content (TOC) relative to other New Albany Shale formations. In much of southern and southeastern Illinois, TOC content of the Grassy Creek 1 has a range of 8.0 to 11.0 percent. However, The TOC range decreases to about 1.0 percent in the western parts of the state (Figure 7).

The Grassy Creek 2 attains its maximum thickness of about 120 feet (36 meter) in southeastern Illinois. It gradually thins northward to about 10 feet (3 m) and the shale intervals laterally pinch out westward (Figure 8). The highest total organic carbon content (TOC) of the Grassy Creek 2 is about 10.0 percent, determine from petrophysical data in southern Illinois (Figure 8).

The Grassy Creek 3, the lowermost part of the Grassy Creek Formation, is mainly restricted to southern and southeastern Illinois. The maximum thickness is 60 feet (18 m) in southern Illinois (Figure 9). The Shale intervals gradually thins and pinch out toward north and west. The highest TOC content of Grassy Creek of about 9.0 percent and is restricted to a small area in in southeastern Illinois (Figure 9).

The Selmier Shale thins gradually westward to less than 10 feet (3 m) where it be indistinguishable from the underlying Blocher Shale and the overlaying Grassy Creek Shale. Eventually, it pinches out against Silurian strata in west part of the state (Figure 10). The organic content of these shales is variable, generally ranging from 1.0 to 11.0 percent (Figure 9). A reduced TOC content of 1.0 to 3.0 percent has been determined primarily from petrophysical data in central Illinois, likely due to change in facies and depositional environment which corresponds to low gamma ray responses.

The thickness map of the Blocher Shale indicates that it is restricted to southeastern and eastern parts of the state. Farther to the north and west, the Blocher thins or grades laterally to the upper portion of the Lingle Formation. The isopach map indicates that the maximum thickness of the Blocher Shale reaches over 40 feet (12 m) in southeastern Illinois (Figure 11). The westward thinning of the formation is either a result of facies transition to Lingle formation and/or subaerial exposure and change in depositional environment (Cluff, et al., 1981). Computed TOC measurements from resistivity logs of over 100 wells indicates that the Blocher Shale consists of an elevated TOC content (up to 9.0%) in southeastern Illinois (Figure 9). Westward, the TOC content decreases, likely due to change in depositional setting and facies transitions. The TOC content is less than 1.0% in central Illinois.

Summary and conclusions

The ΔlogR technique developed by Passey, et al., 1990, was utilized to estimate the total organic carbon (TOC) content of the New Albany Shale Group in Illinois. Petrophysical data, porosity (sonic, porosity, and density) curves were overlaid on the resistivity curves using a shale baseline (a shale interval with minimal organic content) to measure the curve separation for ΔlogR.

The total organic carbon of six wells were calculated using Passey et al., 1990 equations and directly compared to their core-derived TOC data to determine the accuracy and reliability of the petrophysical log-derived measured TOC values. The TOC values computed from the ΔlogR method compare reasonably well with values determined from sample analyses. The deep resistivity values were also plotted against the computed TOC values. The results indicate that there is a logarithmic relationship between those data with a correlation coefficient (R²) over 0.8 or 80%. The high correlation coefficient led us to determine a formula to estimate TOC content of shale intervals within the New Albany Shale Group just using deep resistivity (ILD) petrophysical data.

The New Albany Shale Group has been subdivided into six units to determine thickness and TOC trends: Hannibal-Saverton Shale; Grassy Creek Shale (GK1); Grassy Creek 2 (GK2); Grassy Creek 3 (GK3); Selmier Shale; Blocher Shale. The horizon and unit determinations were based on the petrophysical log characteristics, the depth of formations, lithology, and trace key geophysical horizons and beds.

The petrophysical well logs from over 100 well were utilized to map the thickness distribution and TOC content of the intervals. The TOC data was computed using the generated formula for each zone and horizon. The ability to use only the deep resistivity curve (ILD) to calculate TOC means older logging suites can still be utilized. This option means that many more data points can be utilized to map thickness and TOC trends within the basin. This method provides the opportunity to map in much greater detail the range and areal distribution of TOC throughout the basin. The measurements determined from the New Albany Shale Group intervals and zones indicate that the uppermost Grassy Creek Shale and Blocher Shale intervals contain elevated amounts of organic matter while the Hannibal-Saverton Shale, the lower part of the Grassy Creek Shale and the Selmier Shale, by comparison, contain significantly lower amounts of total organic carbon.

References

Cluff, R. M., M. L. Reinbold, and J. A. Lineback, 1981, The New Albany Shale Group of Illinois: Illinois State Geological Survey Circular 518, 83 p.

Collinson, C., and E. Atherton, 1975, Devonian System, in Handbook of Illinois Stratigraphy: Illinois State Geological Survey Bulletin 95, p. 104–123.Crain, E. R., 2013, Welcome to Crain's Petrophysical Handbook. Online Shareware Petrophysics Training and Refere nce Manual, url http://www.spec2000.net, Accessed.

Lazar, O.R., 2007, Redefinition of the New Albany Shale of the Illinois Basin: An Integrated Stratigraphic, Sedimentologic, and Geochemical Study. (Ph.D. dissertation) University of Indiana, Bloomington (362 pp.)

Mastalerz, M., A. Drobniak, J. Rupp, B. Nuttal, and J. Crockett, 2014; oral presentation, Eastern Unconventional Oil and Gas Symposium. North, W. G., 1969, The Middle Devonian strata of Southern Illinois, ISGS Pub., Circular 441, 49 p.

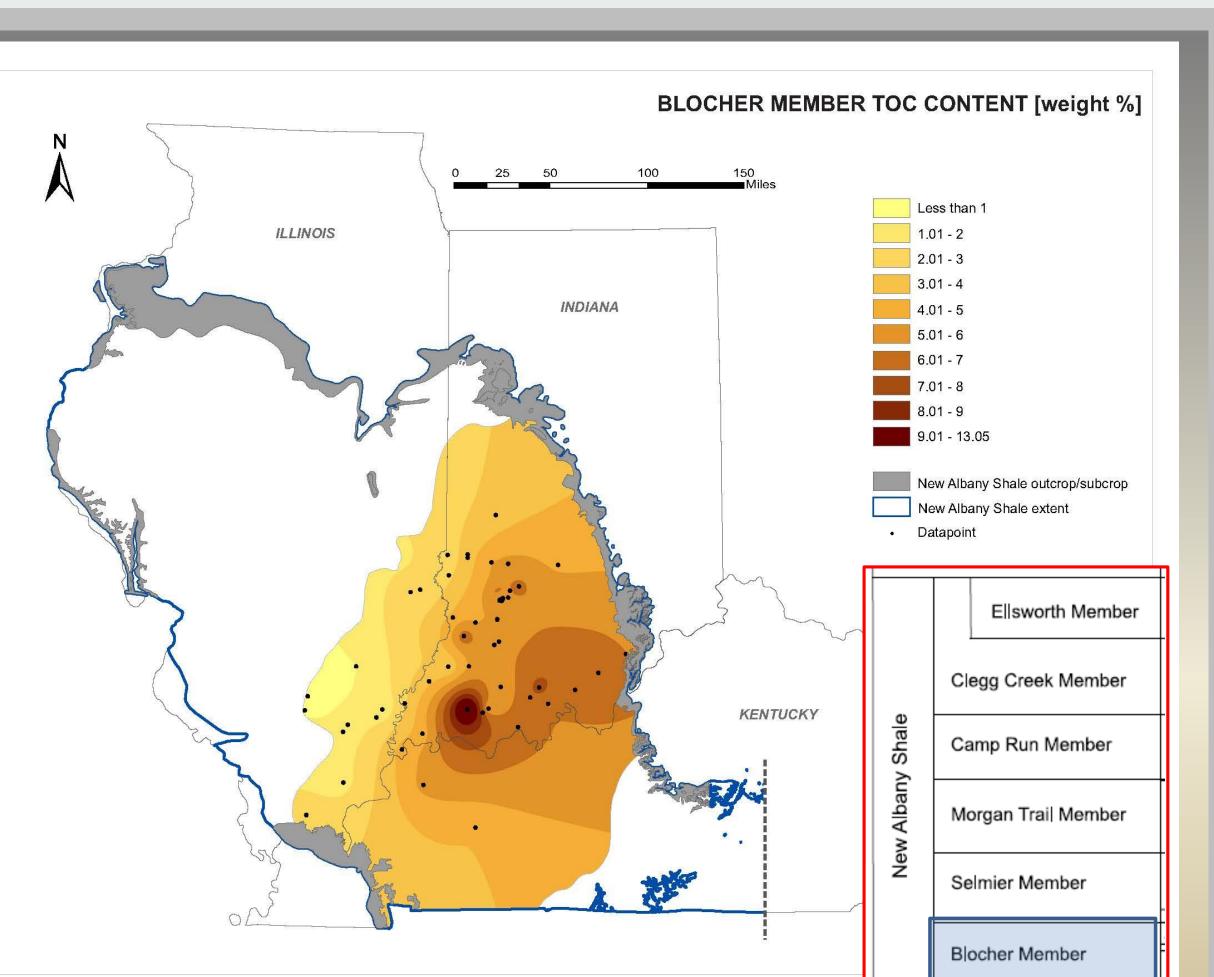
Passey, Q.R., Creaney, S., Kulla, J.B., Moretti, F.J., and Stroud, J.D., 1990, A Practical Model for Organic Richness from Porosity and Resistivity Logs. AAPG Bulletin Vol 74,

No. 12, (December 1990), P. 1777-1794.
Passey, Q.R., Bohacs, K.M., Esch, W.L, and Sinha, S., 2010, From Oil Prone Source Rock to Gas Producing Shale Reservoir – Geologic and Petrophysical Characterization of

Unconventional Shale-Gas Reservoirs. Presented at CPS/SPE International Conference held in Beijing China, June 8-10, 2010. SPE 131350.
Strapoc, D., Mastalerz, M., Schimmelmann, A., Drobniak, A., Hasenmueller, N.R., 2010, Geochemical constraints on the origin and volume of gas in the New Albany Shale (Devo-

nian–Mississippian), eastern Illinois Basin. American Association of Petroleum Geologists Bulletin 94, 1713–1740. Whiting, L.L., and Stevenson, D.L., 1965, The Sangamon Arch. Illinois State Geological Survey, Circular 383.

WORKMAN, L. E., AND GILLETTE, T., 1956, Subsurface stratigraphy of the Kinderhook Series in Illinois: Illinois State Geol. Survey Rept. Investigations 189, 46 p.



Comparison of the TOC map generated by petrophysical data for the Blocher Shale with TOC data from geochemical analyses of the Blocher Shale. In the Illinois portion of the Illinois basin, greater detail of TOC distribution was obtained by using the TOC values derived from petrophysical log analyses.

Figure 12. TOC map utilizing by core (and cuttings)-derived TOC data (Mastalerz, et al., 2014)

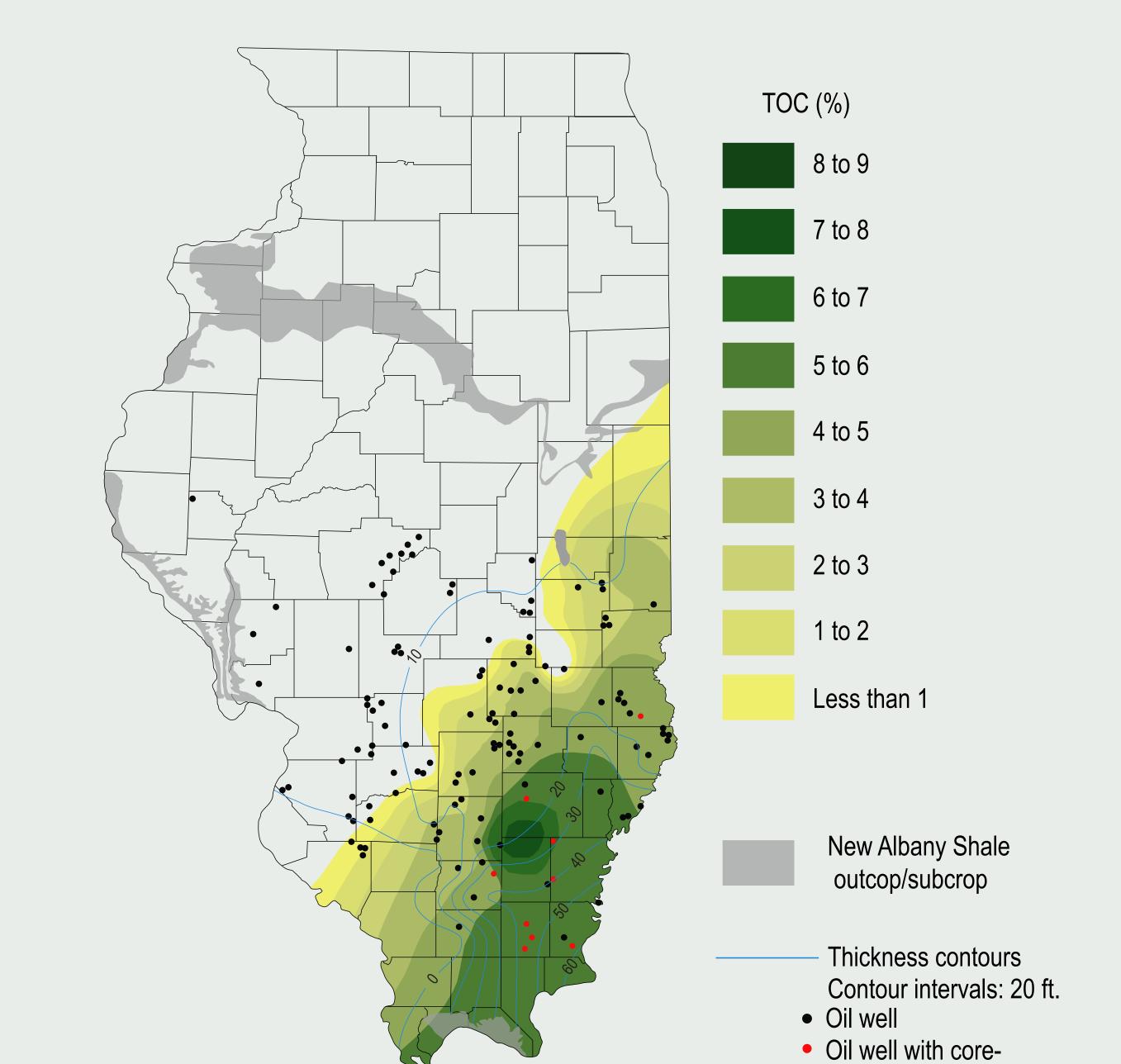


Figure 9. TOC and thickness map of the Grassy Creek 3 (zone 3). Thickness contour intervals are 10 feet (3 meter). TOC intervals are 1.0%. This zone is mainly restricted to southern and southeastern Illinois. The maximum thickness of the formation occurs in southern Illinois. The shale intervals gradually thins and pinches out toward north and west. An approximate maximum of 9.0 percent total organic carbon has been determined in southern Illinois.

N 0 25 50 75 100 125 Miles