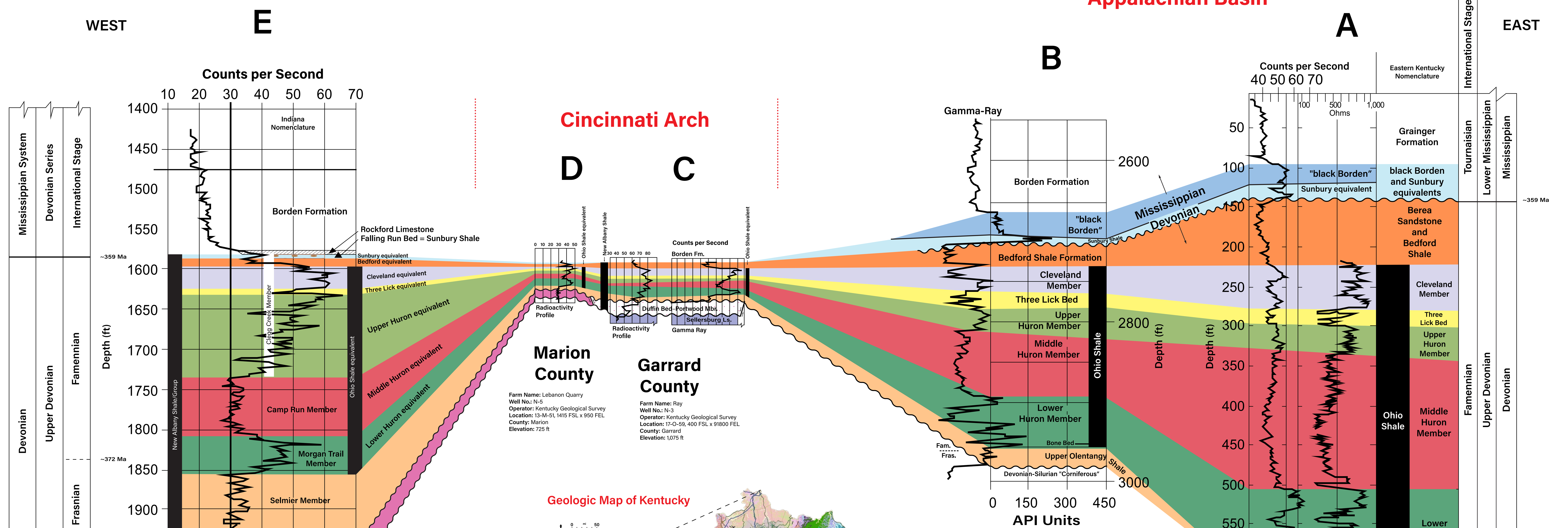
KENTUCKY GEOLOGICAL SURVEY
William C. Haneberg, State Geologist and Director
UNIVERSITY OF KENTUCKY, LEXINGTON

Mississippian-Devonian Black Shales of Kentucky
East-West Transect in Five Cores from the Appalachian Basin to the Illinois Basin

Patrick J. Gooding
Kentucky Geological Survey

and

Frank R. Ettensohn
Department of Earth and Environmental Sciences
University of Kentucky



Crittenden County

Farm Name: Frazer
Well No.: S-1
Operator: Savage Zinc Inc.
Location: 16-K-17, 1650 FSL x 1349 FEL
County: Crittenden
Elevation: 390 ft

Marion County

Farm Name: Lebanon Quarry
Well No.: N-5
Operator: Kentucky Geological Survey
Location: 13-M-51, 1415 FSL x 950 FEL
County: Marion
Elevation: 725 ft

Garrard County

Farm Name: Ray
Well No.: N-3
Operator: Kentucky Geological Survey
Location: 17-O-59, 400 FSL x 91800 FEL
County: Garrard
Elevation: 1,075 ft

Leslie County

Farm Name: Morlandbell Inc.
Well No.: N-3
Operator: Kentucky Geological Survey
Location: 4-H-74, 2050 FSL x 1625 FEL
County: Leslie
Elevation: 1,317 ft

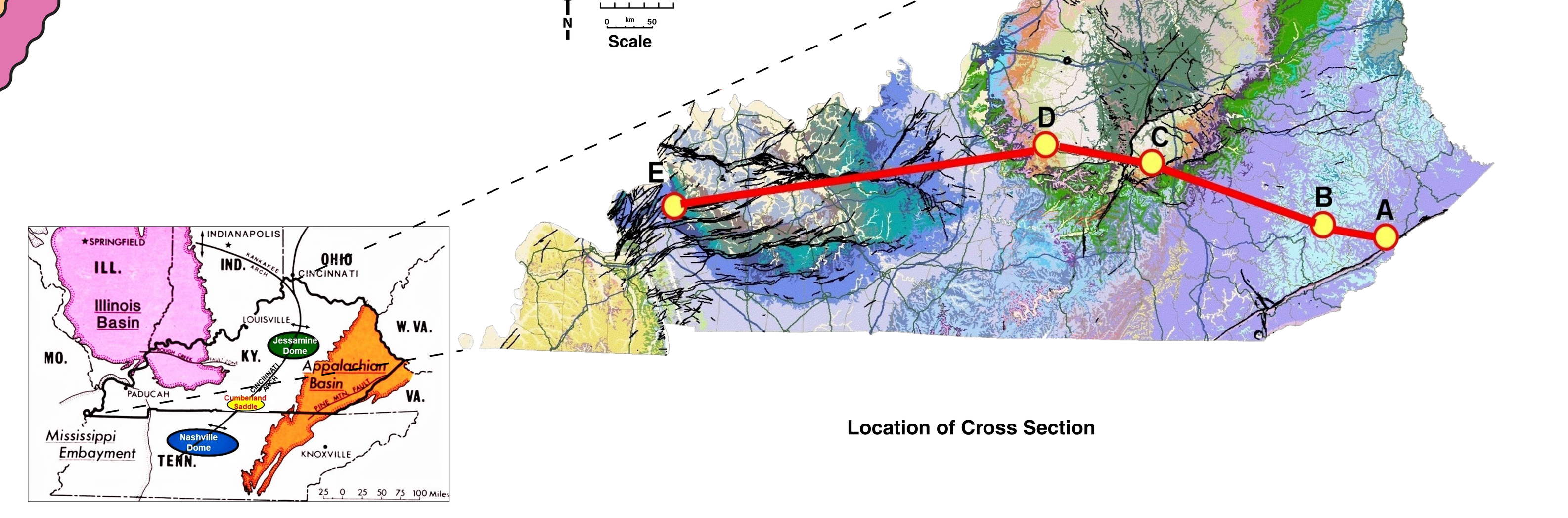
Letcher County

Farm Name: Pine Mountain Tunnel
Well No.: 5
Operator: Kentucky Highway Department (Stokely)
Location: 14-G-80, 3900 FSL x 3720 FEL
County: Letcher
Elevation: 2,161 ft

Datum: Base of Bedford/Berea interval

Horizontal distance between sections not drawn to scale

Geologic Map of Kentucky



Location of Cross Section

Statement of Benefit
This cross section shows the continuity of rock layers and correlations between the Appalachian and Illinois Basins. These relationships could be useful in developing unconventional oil and gas resources in both basins.

Correlating Devonian-Mississippian Black Shales Across the Cincinnati Arch in Kentucky

Devonian-Mississippian black shales are widespread across North America and underlie nearly 70 percent of Kentucky (Kepferle and Roen, 1981; Ettensohn and others, 1988). These black-shale units are among the most thoroughly investigated formations in the commonwealth, because they have sourced most of the conventional hydrocarbons (Gooding and Ettensohn, 2008; Gooding, 2013), have been major producers of gas in both the Illinois and Appalachian Basins, and have major potential as unconventional producers in both basins. In fact, maturation indicators such as vitrinite reflectance and total organic carbon, from both basins, show that the shales are mostly mature and had a high potential to generate hydrocarbons (East and others, 2012; Gooding, 2013; Ryder and others, 2013). In Kentucky, however, temporal and stratigraphic relationships between basins differ, and the units in each basin are known by different names, making cross-basin correlations difficult (Ettensohn and others, 1988). Thus, the purpose of this chart is to provide preliminary interbasinal correlations based on five cores (A–E) available at the Kentucky Geological Survey Earth Analysis Research Library. This chart correlates organic-rich shales across the Cincinnati Arch via radioactive stratigraphy and supplemental biostratigraphic control. Where available, commercial gamma-ray logs were used for correlation, but where unavailable, artificial gamma-ray logs, or radioactivity profiles, were produced using a handheld scintillometer (Ettensohn and others, 1979).

Gamma-ray logs are the principal means of correlation in black shales, since most black shales look alike. Abundant organic matter gives these shales their dark color, but the organic matter is not uniformly distributed and occurs in distinct stratigraphic intervals of "hot" radioactive shales interbedded with gray shales or black shales that are not as radioactive—hence, "cold." Informal radioactive units (colored intervals on chart) have been designated and related to the formal stratigraphic units used on the chart (Provo and others, 1978); many of these hot and cold units can be correlated for more than 1,000 km using gamma-ray logs (Kepferle and others, 1978). Thus, this chart effectively correlates widespread, radioactive units, because radioactivity is an indicator of organic-rich shales capable of producing hydrocarbons. In earlier work, the U.S. Department of Energy established a +20 API unit gamma-ray shift (approximately 5 counts per second or 120 ohms) or higher above the Three Lick Bed line as an indicator of hot, radioactive shales (Dillman and Ettensohn, 1981). Based on this guideline, in the Appalachian Basin, the Sunbury and Upper and Lower Huron Members of the Ohio Shale are suitable targets, whereas in the Illinois Basin, nearly the entire Grassy Creek and Morgan Trail Members of the New Albany Shale/Group are possible targets. Hence, this nearly east-west, 480-mi-long section can be used to discern critical units, understand them, and correlate them via gamma-ray logs.

Chronostratigraphic stages and their approximate absolute ages (Ogg and others, 2016) are provided to help explain temporal relationships between the basins, but the association of these stages with definite lithostratigraphic units, especially in the Illinois Basin, is problematic. In Kentucky parts of the Illinois Basin, both Illinois and Indiana unit names are used, and unit names are largely based on shale color: either gray, black, or some combination. We also know, however, that shale color in any one unit can change relative to depositional environment (Ettensohn and Elam, 1985), meaning that as units thicken or thin during color changes, any associated chronostratigraphy may also change. Other data on shale correlations can be found in Ettensohn and others (1988, 1989), Sandberg and others (1994), Over (2002, 2007), and Over and others (2009).

Not only do the names and relative ages of the shales change across the Cincinnati Arch, but the thicknesses of the shales and their subunits also change. In western Kentucky parts of the Illinois Basin, the shales attain a maximum thickness of 472 ft (Shaver, 1985), although the thickness of shales in core E is about 390 ft. In contrast, in eastern Kentucky parts of the Appalachian Basin, the entire black-shale sequence is approximately 1,800 ft thick (Dillman and Ettensohn, 1980), but in core A, which is cut off at the bottom by a thrust fault, the entire sequence has a thickness of 545 ft. Between the basins in the Cincinnati Arch region of central Kentucky, the shale thins to around 60 ft in core C and to less than 45 ft in core D. Farther south on the arch in Kentucky, the shale thins to 4 ft (Cattermole, 1963).

In the area of thinning across the Cincinnati Arch, the unique Portwood Member of the Borden Formation (core C), which is partially equivalent to the Blocher Member of the New Albany Shale/Group in the Illinois Basin (cores D and E), occurs at the base of the New Albany Shale/Group. The Portwood is unusual in that it is Middle Devonian (Givetian) in age, and not only contains organic-rich black shale, but also organic-rich, fossiliferous dolostones, sandstones, and breccias that occur in small, fault-bound basins (Ettensohn and others, 1991). In the Illinois Basin, the Blocher is much more widespread and also contains younger Late Devonian (Frasnian) strata.

Although erosion has destroyed evidence of shales across northern parts of the Cincinnati Arch, Devonian-Mississippian black shales are preserved near the present-day axis of the arch in Garrard County, Ky. (core C), so thinned shales may have been deposited everywhere across the arch. Based on total section thickness, the Devonian axis of the arch apparently passed near Marion County, Ky. (core D), and was apparently not the same as the present-day or late Paleozoic axis. Thus, the axes of the arch changed through time, and during Devonian–Early Mississippian time, much of the arch area appears to have been an uplifted platform across which the thinned black-shale units were deposited (cores C and D). By late Frasnian time, Acadian orogenic loading from the east depressed the arch area so much that the Appalachian Basin yoked with the Illinois Basin, permitting Appalachian Basin lithologies to cross the arch into the Illinois Basin (Ettensohn, 1998). The first units to join across the arch were gray shales of the Upper Olentangy and Selmier Members of the New Albany, but as subsidence continued, organic-rich dark shales (Morgan Trail Member of the New Albany) similar to those in the Appalachian Basin crossed the arch into the Illinois Basin. This cross section also shows that prior to basin yoking, the Cincinnati Arch isolated the two basins so that the history of shale deposition in them was partly different.

Black shales in both basins have traditionally been inferred to represent slow deposition in deep anoxic waters distal to Catskill clastics on the eastern margin of the continent (Ettensohn and Barron, 1981; Ettensohn and others, 1988; de Witt and others, 1993; Kepferle, 1993). Studies of trace elements, as well as of carbon, oxygen, and sulfur isotopes, have suggested variable oxygen conditions during deposition, however, from anoxic to dysaerobic to oxic (Sageman and others, 2003; Rimmer, 2004; Perkins and others, 2008). The inference of regional deep-water environments because of anoxia has been challenged in recent years. In at least some areas, shallower water depths have also been interpreted (Schieber, 1994, 1998; Schieber and Riciputi, 2004; Alsharani and Evans, 2014). In addition, as Ettensohn and others (1988) have demonstrated, the mineralogical composition of gray and black shales in these sequences is essentially the same, except for the presence of abundant organic matter in the black shales. The presence or absence of organic matter, moreover, has been interpreted as representing the position of the paleo-pycnocline (level at which O_2 declines rapidly) between relatively deeper, downdip, anoxic water, in which organic matter is largely preserved, and shallower, updip, dysaerobic to oxic waters, in which most organic matter is destroyed (Cluff, 1980; Ettensohn and Elam, 1985). Such changes relative to changing water depth suggest that the alternation of hot, organic-rich black shales with the cold, organic-poor gray shales observed in these sequences may merely reflect changing sea level or circulation patterns.

References Cited

Alsharani, S., and Evans, J.E., 2014, Shallow-water origin of a Devonian black shale, Cleveland Shale Member (Ohio Shale), northeastern Ohio, USA: Open Journal of Geology, v. 4, p. 636–653.

Cattermole, J.M., 1963, Geology of the Waterview quadrangle, Kentucky: U.S. Geological Survey 7.5-Minute Geologic Quadrangle Map GQ-286, scale 1:24,000.

Cluff, R.M., 1980, Paleoenvironment of the New Albany Shale Group (Devonian-Mississippian) of Illinois: Journal of Sedimentary Research, v. 50, p. 767–780.

DeWitt, W., Jr., Roen, J.B., and Wallace, L.G., 1993, Stratigraphy of the Devonian black shales in the Appalachian Basin, *in* Roen, J.B., and Kepferle, R.C., eds., Petroleum geology of the Devonian and Mississippian black shales of eastern North America: U.S. Geological Survey Bulletin 1909, p. B1–B57.

Dillman, S.B., and Ettensohn, F.R., 1980, Isopachous map of the Devonian black-shale sequence (New Albany-Chattanooga-Ohio Shale) in eastern Kentucky: U.S. Department of Energy, Morgantown Energy Technology Center, METC/EGSP 515, scale 1:370,000.

Dillman, S.B., and Ettensohn, F.R., 1981, Isopach map of highly radioactive black shale in the Three Lick Bed and Huron Shale Member of the Ohio Shale in Kentucky: U.S. Department of Energy, Morgantown Energy Technology Center, METC/EGSP 505, scale 1:370,000.

East, J.A., Swezey, C.S., Repetski, J.E., and Hayba, D.O., 2012, Thermal maturity map of Devonian shale in the Illinois, Michigan, and Appalachian Basins of North America: U.S. Geological Survey Scientific Investigations Map 3214, scale 1:24,000.

Ettensohn, F.R., 1998, Compressional tectonic controls on epicontinental black-shale deposition: Devonian-Mississippian examples from North America, *in* Schieber, J., Zimmerle, W., and Sethi, P., eds., Shales and mudstones: Basin studies, sedimentology, and paleontology: Stuttgart, E. Schweizerbart'sche Verlagsbuchhandlung, v. 1, p. 109–128.

Ettensohn, F.R., Barnett, S.F., and Norby, R.D., 1991, Middle Devonian black shales in Kentucky, *in* Proceedings, 1990 Eastern Oil Shale Symposium: University of Kentucky Institute for Mining and Minerals Research, p. 218–226.

Ettensohn, F.R., and Barron, L.S., 1981, Depositional model for the Devonian-Mississippian black shales of North America: A paleoclimatic approach, *in* Roberts, T.G., ed., GSA Cincinnati '81 field trip guidebooks: American Geological Institute, v. 11, p. 344–361.

Ettensohn, F.R., and, Elam, T.D., 1985, Defining the nature and location of a Late Devonian–Early Mississippian pycnocline in eastern Kentucky: Geological Society of American Bulletin, v. 96, p. 1313–1321.

Ettensohn, F.R., Fulton, L.P., and Kepferle, R.C., 1979, Use of scintillometer and gamma-ray logs for correlation and stratigraphy in homogeneous black shales: Geological Society of America Bulletin, v. 90, p. 828–849.

Ettensohn, F.R., Goodmann, P.T., Norby, R.D., and Shaw, T.H., 1989, Stratigraphy and biostratigraphy of the Devonian-Mississippian black shales in west-central Kentucky and adjacent parts of Indiana and Tennessee, *in* Proceedings, 1988 Eastern Oil Shale Symposium: University of Kentucky Institute for Mining and Minerals Research, p. 237–245.

Ettensohn, F.R., Miller, M.L., Dillman, S.B., Elam, T.C., Geller, K.L., Swager, D.R., Markowitz, G., Woock, R.D., and Barron, L.S., 1988, Characterization and implications of the Devonian-Mississippian black-shale sequence, eastern and central Kentucky, U.S.A.: Pycnoclines, transgression, regression, and tectonism, *in* McMillan, N.M.J., Embry, A.F., and Glass, D.J., eds., Devonian of the world, proceedings of the Second International Symposium on the Devonian System: Canadian Society of Petroleum Geologists Memoir 14, v. 2, p. 323–345.

Gooding, P.J., 2013, Unconformity, karst, hydrocarbons, minerals, environments and structures present in the Cambrian-Ordovician Knox Group in Kentucky, *in* Derby, J.R., Fritz, R.D., Morgan, W.A., and Sternbach, A., eds., The great American carbonate bank: The geology and petroleum potential of the Cambrian-Ordovician Sauk Sequence of Laurentia: American Association of Petroleum Geologists Memoir 98, p. 1103–1164.

Gooding, P.J., and Ettensohn, F.R., 2008, Hydrocarbons sourced from Mississippian-Devonian black shales in the Appalachian and Illinois Basins [abs.]: American Association of Petroleum Geologists Search and Discovery Article 90078, www.searchanddiscovery.com/abstracts/html/2008/annual/abstracts/413025.htm [accessed 11/14/2018].

Kepferle, R.C., 1993, A depositional model and basin analysis for gas-bearing black shale (Devonian and Mississippian) in the Appalachian Basin, *in* Roen, J.B., and Kepferle, R.C., eds., Petroleum geology of the Devonian and Mississippian black shale of eastern North America: U.S. Geological Survey Bulletin, v. 1909, p. F1–F23.

Kepferle, R.C., and Roen, J.B., 1981, Chattanooga and Ohio Shales of the southern Appalachian Basin, *in* Roberts, T.G., ed., GSA Cincinnati '81 field trip guidebooks: American Geological Institute, v. II, p. 259–323.

Kepferle, R.C., Wilson, E.N., and Ettensohn, F.R., 1978, Preliminary stratigraphic cross section showing radioactive zones in the Devonian black shales in the southern part of the Appalachian Basin: U.S. Geological Survey Chart OC-85, 1 sheet.

Ogg, J.G., Ogg, G.M., and Gradstein, F.M., 2016, A concise geologic time scale 2016: Amsterdam, Elsevier, 234 p.

Over, D.J., 2002, The Frasnian/Famennian boundary in central and eastern United States: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 181, p. 153–169.

Over, D.J., 2007, Conodont biostratigraphy of the Chattanooga Shale, Middle and Upper Devonian, southern Appalachian Basin, eastern United States: Journal of Paleontology, v. 81, p. 1194–1217.

Over, D.J., Lazar, R., Baird, G.C., Schieber, J., and Ettensohn, F.R., 2009, *Protosalvinia* Dawson and associated conodonts of the Upper *trachytera* Zone, Famennian, Upper Devonian in the eastern United States: Journal of Paleontology, v. 83, p. 70–79.

Perkins, R.B., Piper, D.Z., and Mason, C.E., 2008, Trace-element budgets in the Ohio/Sunbury Shales of Kentucky: Constraints on ocean circulation and primary productivity in the Devonian-Mississippian Appalachian Basin: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 265, no. 1, p. 14–29.

Provo, L.J., Kepferle, R.C., and Potter, P.E., 1978, Divisions of the black Ohio Shale in eastern Kentucky: American Association of Petroleum Geologists Bulletin, v. 62, p. 1703–1713.

Rimmer, S.M., 2004, Geochemical paleoredox indicators in Devonian-Mississippian black shales, central Appalachian Basin (USA): Chemical Geology, v. 206, no. 3, p. 373–391.

Ryder, R.T., Hackley, P.C., Alimi, H., and Trippi, M.H., 2013, Evaluation of thermal maturity in low maturity Devonian shales of the northern Appalachian Basin: American Association of Petroleum Geologists Search and Discovery Article 10477.

Sageman, B.B., Murphy, A.E., Werne, J.P., Ver Straeten, C.A., Hollander, D.J., and Lyons, T.W., 2003, A tale of shales: The relative roles of production, decomposition, and dilution in the accumulation of organic-rich strata, Middle–Upper Devonian, Appalachian Basin: Chemical Geology, v. 195, p. 229–273.

Sandberg, C.A., Hassenmueller, N.R., and Rexroad, C.B., 1994, Conodont biochronology, biostratigraphy, and biofaces of Upper Devonian part of the New Albany Shale, Indiana: Courier Forschungsinstitut Senckenberg, v. 168, p. 227–253.

Schieber, J., 1994, Evidence for high-energy events and shallow-water deposition in the Chattanooga Shale, Devonian, central Tennessee, USA: Sedimentary Geology, v. 93, no. 3, p. 193–208.

Schieber, J., 1998, Developing a sequence stratigraphic framework for the Late Devonian Chattanooga Shale of the southeastern USA: Relevance for the Bakken Shale, *in* Christopher, J.E., Gilboy, C.F., Paterson D.F., and Bend, S.L., eds., Eighth International Williston Basin Symposium: Saskatchewan Geological Society Special Publication 13, p. 58–68.

Schieber, J., and Riciputi, L., 2004, Pyrite ooids in Devonian black shales record intermittent sea-level drop and shallow-water conditions: Geology, v. 32, no. 4, p. 305–308.

Shaver, R.H., 1985, Midwestern Basin and Arches Region: American Association of Petroleum Geologists Correlation of Stratigraphic Units of North America Project, COSUNA Chart MBA, 1 sheet.

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Cores are available for study at the University of Kentucky
Kentucky Geological Survey
Earth Analysis Research Library
2500 Research Park Drive
Lexington, KY 40511
www.uky.edu/KGS/core_library