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Structure and Isopach Maps of the Mississippian "Big Lime" (Newman Limestone/Slade Formation), Eastern Kentucky

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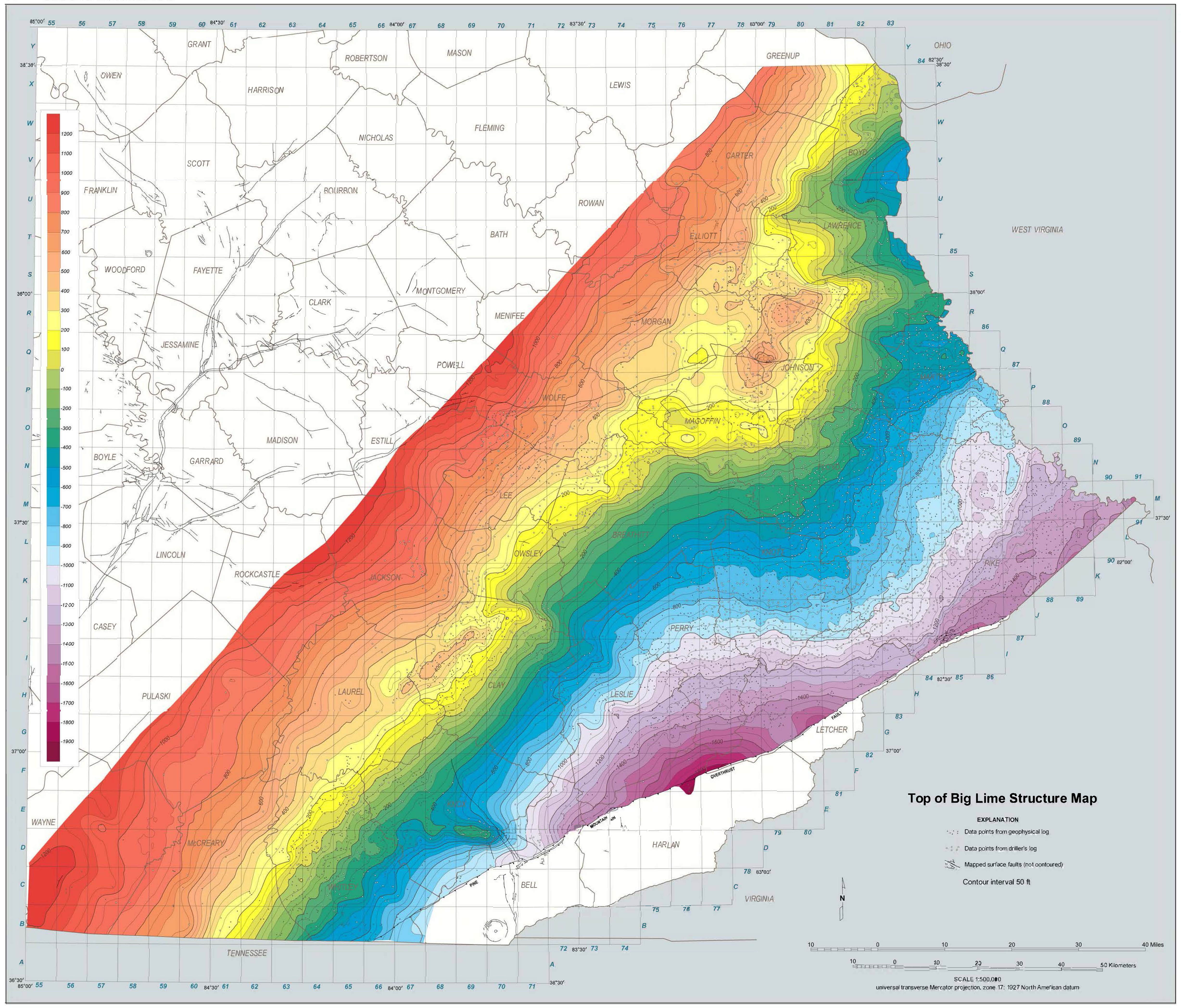

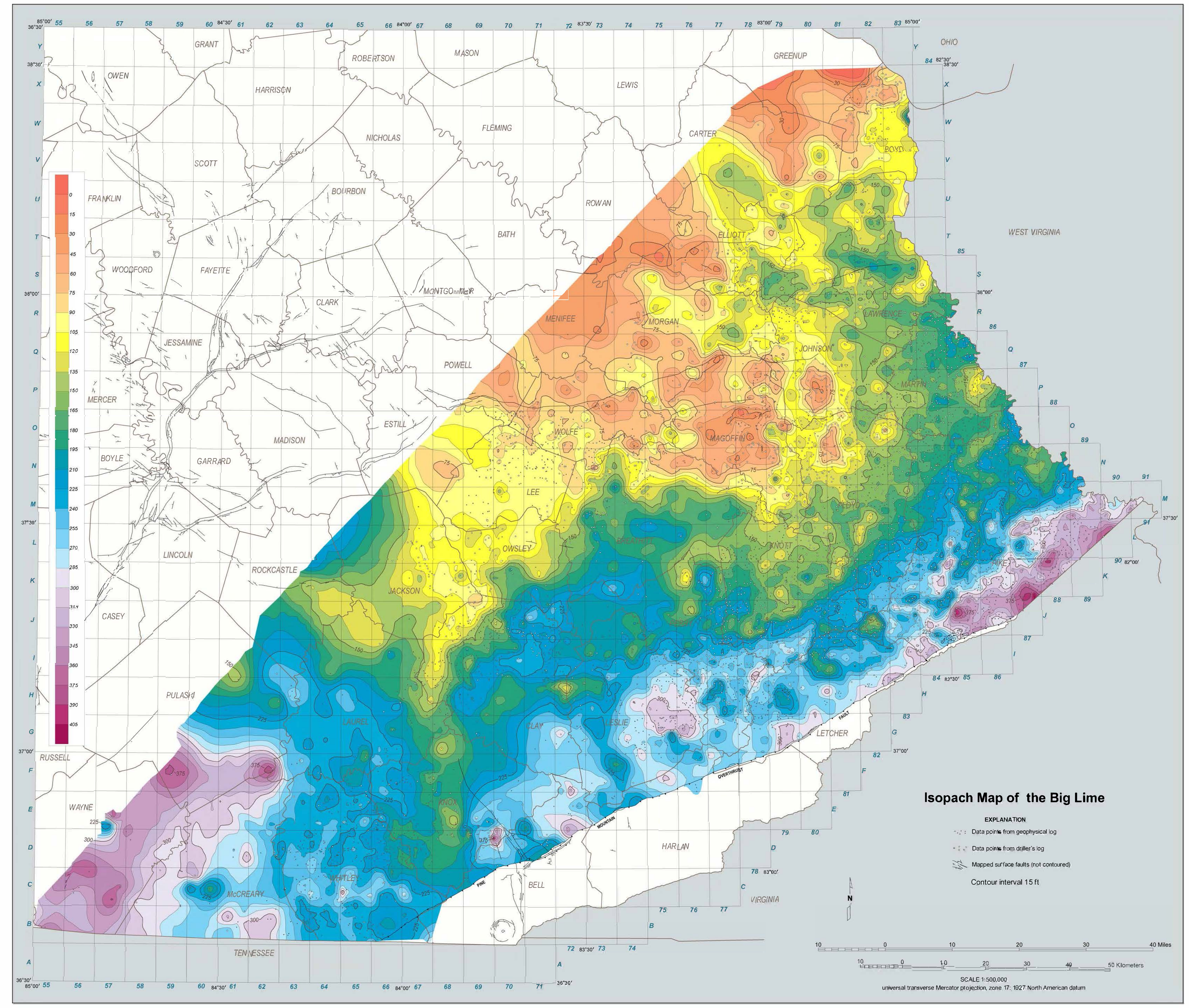

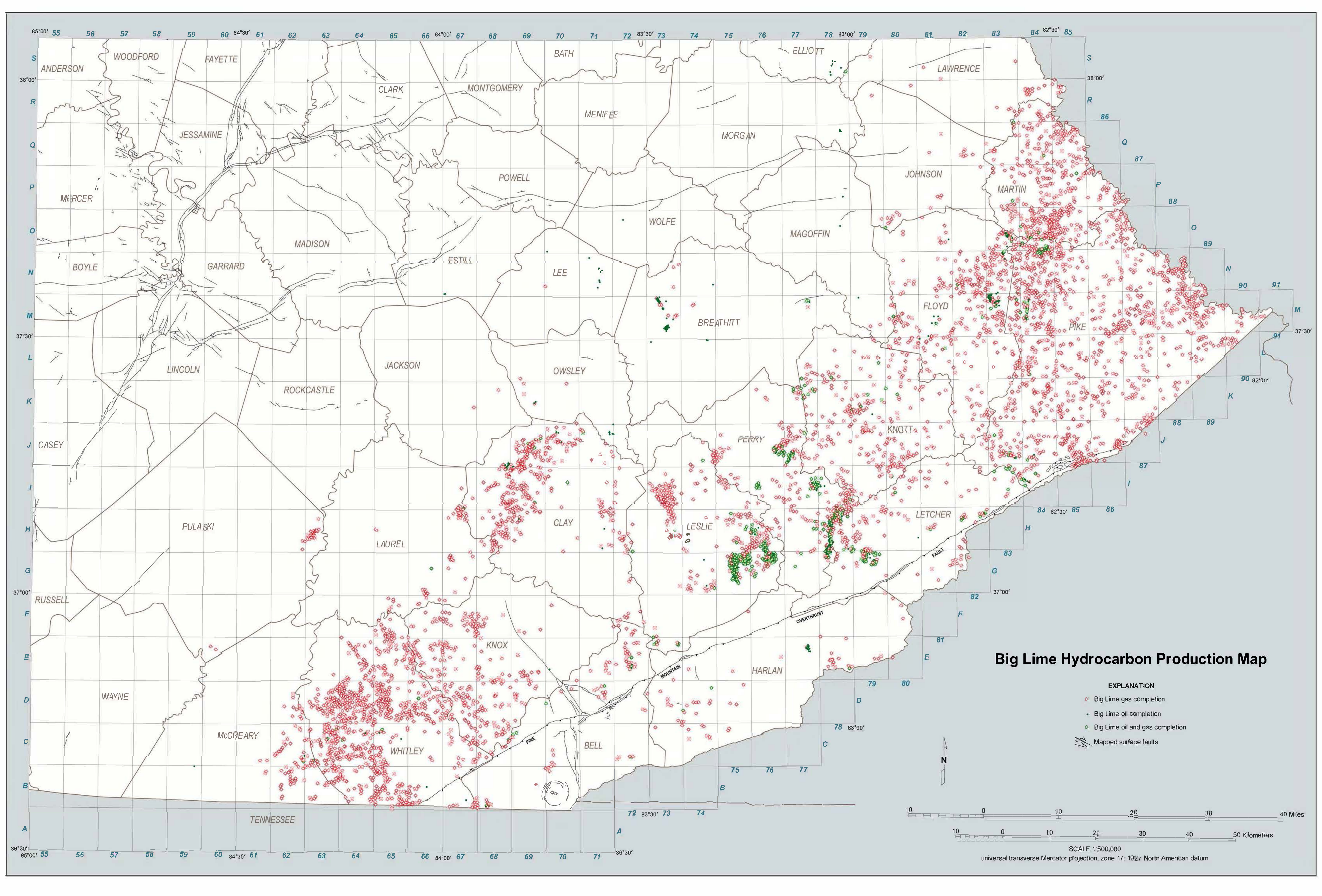

Type Geophysical Log

Eastern Kentucky Production Co. KF1001 EKPC Fee

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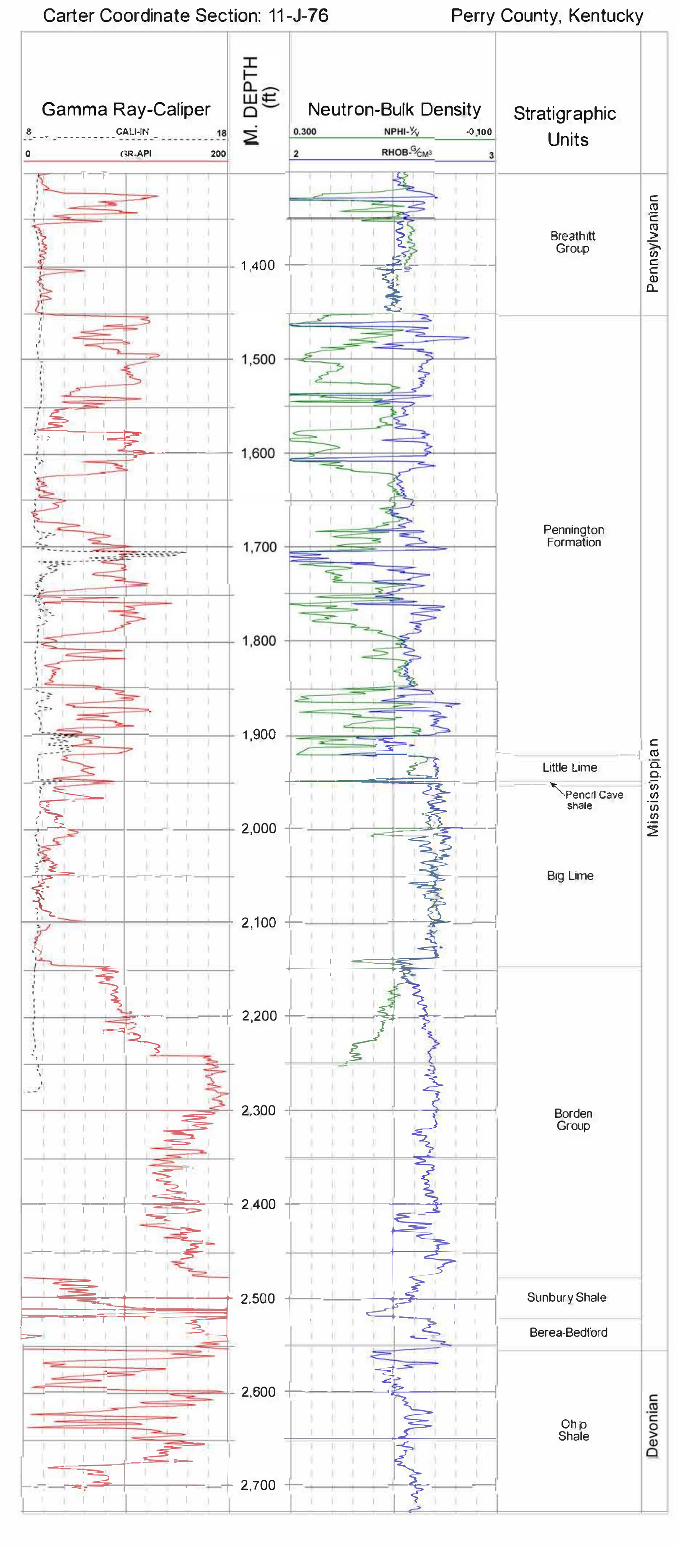
Carter Coordinate Section: 11-J-76 Perry County, Kentucky



Structure and Isopach Maps of the Mississippian "Big Lime" (Newman Limestone/Slade Formation), Eastern Kentucky

David C. Harris and Thomas N. Sparks

Introduction

The maps included in this publication were made using stratigraphic data collected by us from almost 8,000 wells as part of a regional stratigraphic study of the Mississippian Slade Formation in eastern Kentucky. The data extend from the Mississippian outcrop belt along the northwestern edge of the map area, to the state borders on the northeast. The southeastern border of the map area is marked by the Pine Mountain Fault.

Formation tops data for these wells were collected from geophysical (electric) logs and drillers' logs, and are available in electronic format from the Kentucky Geological Survey (Harris and Sparks, 1997). In the subsurface this stratigraphic interval is commonly referred to as the "Big Lime" by drillers. Because this term is widely used in the oil and gas industry, it will be used in this publication.

Regional geologic cross sections for the mapped area by Harris and Sparks (2000) were previously published. These structural and stratigraphic cross sections were constructed from geophysical well logs and provide additional data (lithology, porosity) for the Big Lime.

These structure and isopach maps illustrate the structural configuration and thickness, respectively, of the Mississippian Slade Formation (Newman Limestone or Big Lime). Data points used to make the maps are shown. The maps include both color shading and labeled contours. The structure map is contoured with a 50-ft interval, and the isopach with a 15-ft interval.

Methodology

Elevation of the top of the Slade Formation was interpreted from geophysical and drillers' logs from selected wells in eastern Kentucky. Wells used in the study were selected based on their location, data type, and age. In many parts of the study area there are more wells than are shown on the map. Where both data types were available, geophysical logs (gamma ray, bulk density, neutron) were preferred over drillers' logs. Density of well data was limited to an average maximum of two wells per Carter coordinate section. For the top of the Big Lime structure map, 6,577 data points were used. For the isopach map, 6,401 data points were used. Stratigraphic picks are illustrated on the type geophysical log.

The structure and isopach maps were contoured by computer using Petra mapping software from Geoplus Inc. The maps are contoured from computer-calculated data grids, derived from the actual data points. Because the interpolated grid is contoured, rather than the actual data points, there may be some discrepancies between contour lines and data points. The data grid for the structure map was calculated using a minimum curvature algorithm. Because this method produced undesirable closures in areas of sparse data, a grid calculated using a least squares algorithm was substituted in areas of sparse data. Grid nodes were calculated using an octant search method, with a maximum of two wells used per octant. A minimum curvature tension factor of 1 was used. The isopach map was gridded using a least-squares algorithm, with an octant search method, two wells per octant. The isopach grid was flexed (smoothed) with a flex factor of 2. The grid size for both maps is 272 columns by 211 rows, with a grid cell size of 1,000 m. Thus, features smaller than the grid cell size will not be resolved on these maps.

Limitations of the Maps

These maps should be interpreted in light of the limitations of computer-based gridding and contouring. First, data density varies widely across the area. In areas of sparse data, values are extrapolated, often over large distances, from neighboring wells. Caution should be used in these areas. In particular, closed high and low features may be artifacts of the gridding process in areas of poor control. Data quality also varies across the study area, because of the source of the formation picks. The data source is indicated by the well symbol shown on the maps. Solid circles indicate data obtained from geophysical logs (more accurate), and open circles indicate data from drillers' logs. As is the case with all grid-based maps, some data points may not be honored by the contours. The triangulation-based gridding method used for these maps was chosen to minimize this problem.

Subsurface faults were not interpreted in these maps. Mapped surface faults are shown in red, but these features were not included when the data were contoured. Surface faults are shown only for reference, since most of these faults extend to the Mississippian and will affect the Big Lime. In some areas, the presence of a subsurface fault can be inferred by sharp deflections and tight spacing of contours.

Stratigraphy

The Big Lime is a drillers' term for Mississippian limestones and dolostones equivalent to several formations defined from outcrop exposures in eastern Kentucky. Much previous work, including published geologic quadrangle maps, refers to this interval as the Newman Limestone. More recent work limits the Newman Limestone to outcrops along Pine Mountain, and assigns carbonates in east-central Kentucky to the Slade Formation (Ettensohn and others, 1984). The surface mapped in this project lies within the Newman and Slade Formations. The maps do not represent the top or total thickness of these formations. The top of the Big Lime occurs at the base of the drillers' Pencil Cave shale, which is equivalent to the Hardinsburg Sandstone of McFarlan and Walker (1956) and the Maddox Branch Member of the Slade Formation (Ettensohn and others, 1984) (see type log). The Pencil Cave shale is an excellent subsurface stratigraphic marker, making the top of the Big Lime a consistent horizon on which to correlate. It is easily recognized on geophysical logs, and was commonly noted by drillers in wells without modern logs. The Pencil Cave shale is overlain by the drillers' Little Lime, a thinner limestone unit (10 to 100 ft thick) that is equivalent to the Glen Dean Limestone of McFarlan and Walker (1956) and the Poppin Rock Member of the Slade Formation (Ettensohn and others, 1984). The Little Lime has limited reservoir potential, and is not included on these maps. The Big Lime is equivalent to the Greenbriar Limestone in Virginia and West Virginia (Smosna, 1996; Wynn and Read, 1999, 2003). Recent sequence-stratigraphic interpretations of the Mississippian carbonate interval include those by Al-Tawil (1998), Wynn and Read (1999, 2003), and Smith and others (2001).

The base of the Big Lime is defined as the contact with the Mississippian Borden Formation in most of the study area. In the southwestern part of the mapped area, the Big Lime is underlain by the Warsaw Limestone or Fort Payne Formation.

Structure

The Big Lime was influenced by both syndepositional and post-depositional tectonic activity. A comprehensive review of structural studies on the Mississippian in eastern Kentucky is given in Dever (1999). Dever (1999) documented erosional features, depositional thinning, and thickness variations along the Mississippian outcrop belt in east-central Kentucky as evidence for coeval tectonic activity. Similar tectonic activity is likely in the subsurface area covered by this map.

The most obvious feature of the structure map is the regional dip of the Big Lime from northwest to southeast. This dip direction is toward the central part of the Appalachian Basin, and resulted from post-Mississippian subsidence of the central part of the basin. The Big Lime surface dips from elevations of over +1,200 ft along the northwestern erosional edge, to just below –1,900 ft along the southeastern edge of the map (sea level datum). Interrupting this regional dip are several prominent structures. Most obvious is the Paint Creek Uplift (Hudnall and Browning, 1924), which consists of an anticline in Johnson, Morgan, and Magoffin Counties, and a nose extending south into Letcher and Pike Counties. Northwest of the uplift is a syncline striking northeast–southwest. This feature corresponds to a shallower structure, the Allegheny Synclinorium, mapped by Chesnut (1992) on the Pennsylvanian Fire Clay coal horizon.

The other major structure is the Rockcastle River Uplift in northern Clay and eastern Laurel Counties. This anticline lies on the upthrown side of the northeast–southwest-trending Rockcastle River Fault, which forms part of the southern boundary of the Cambrian Rome Trough (McGuire and Howell, 1963; Webb, 1980; Maynor and MacQuown, 1983). Although the Rockcastle River Fault is predominantly downthrown to the northwest, it has a complex history of reactivation and reversal (White and Drahovzal, 2001). The northern end of this structure is marked by a sharp right-angle deflection in structural contours along the Clay-Owsley County border, indicating a northwest–southeast-trending fault roughly orthogonal to the Rockcastle River Fault. This subsurface fault was previously recognized by Maynor (1984) and named the Right Fork Fault. This fault has been mapped at the Precambrian basement level by Drahovzal and Noger (1995).

Other structures apparent on the map include the Artemus Anticline in Knox County and a smaller anticline in Pike County associated with the D'Invilliers Fault (Lee, 1980; Drahovzal and Noger, 1995). The Artemus Anticline lies west of the White Mountain Fault and trends east–west, diverging significantly from the fault trend. The D'Invilliers structure is interpreted as a left-lateral strike-slip fault on the basement map of Drahovzal and Noger (1995).

The structure of Pennsylvanian rocks in eastern Kentucky differs significantly from that of underlying Devonian and Mississippian units. As mapped by Chesnut (1992, Fig. 15), Pennsylvanian rocks dip to the northwest from the Pine Mountain Fault, into a northeast–southwesttrending syncline located south of the Paint Creek Uplift (the Eastern Kentucky Syncline). The northwest dip is opposite from that of the underlying Big Lime structure. Based on the present relief on the Fire Clay coal, there has been a minimum of 1,600 ft of post-Pennsylvanian uplift along the southeastern edge of Kentucky. Structure at the Big Lime level shows no indication of the Eastern Kentucky Syncline or differential uplift in the southeastern part of the study area.

Thickness of the Big Lime

The thickness values were calculated from stratigraphic tops data for the Big Lime and the underlying unit (the Borden Formation, Warsaw Limestone, or Fort Payne Formation). Thickness of the Big Lime ranges from 1 ft (from drillers' log data on the Paint Creek Uplift in Magoffin County) to 427 ft in southeastern Pike County. The Big Lime in general thickens toward the southeast and southwest, parallel with structural strike. This thickening resulted from greater subsidence in the central Appalachian Basin during deposition.

Deviations in thickness from the regional trend are common. Thickness of the Big Lime was influenced by four main factors: regional subsidence, preexisting erosional topography, coeval tectonics, and post-Mississippian erosion. For a more in-depth discussion of tectonic effects on Mississippian carbonate deposition, see Dever (1999). A large area of thinning is centered in Magoffin County, and extends to the east into Johnson and Floyd Counties, and south into Knott County. This area of thinning generally corresponds to the Paint Creek Uplift, although it is offset to the south and west from the present-day crest of the structure. Thinning over the Paint Creek Uplift is the result of both depositional thinning and erosion at the pre-Pennsylvanian unconformity. Cross sections over the uplift document this erosion; Big Lime carbonates are directly overlain by Pennsylvanian sandstones (Harris and Sparks, 2000). The thinning indicates the uplift was positive during the Mississippian, and remained so through the Pennsylvanian. The offset between the area of maximum thinning and the present crest of the Paint Creek structure suggests the structure may have shifted since the Mississippian. The thin areas along the northwestern edge of the study area in Rowan, Elliott, Morgan, and Wolfe Counties lie along the Waverly Arch (Woodward, 1961), which was a positive feature during the Mississippian (Ettensohn, 1981; Dever, 1999).

Thinning of the Big Lime is also apparently associated with the Rockcastle River Uplift around the intersection of Clay, Jackson, and Owsley Counties. As noted for the Paint Creek Uplift, the area of maximum thinning does not coincide with the present-day crest of the Rockcastle River Uplift. The present anticlinal structure is located southeast of the main area of thinning. The western end of this Big Lime thin turns south and crosses the anticline, continuing to form a distinct linear thin extending south to the Artemus structure on the west side of the White Mountain Fault in Knox County. The thin is not reflected on the Big Lime structure map, but may be associated with a subsurface extension of the White Mountain Fault.

The Big Lime also thins somewhat across the Perry County Uplift, in northern Perry County and southern Breathitt County. The Perry County Uplift is a fault-bounded basement high that developed in the Cambrian, forming part of the southern boundary of the Rome Trough (Ammerman and Keller, 1979). Thinning across this structure was also noted by Pear (1980). This indicates some reactivation of the uplift during the Mississippian. Thinning over a similar-age structure in Pike County (the Pike County Uplift) is not apparent on the Big Lime isopach map. The Pike County structure does not appear to have influenced Big Lime deposition.

The southeastern edge of the mapped area shows some linear northwest–southeast-oriented trends in thickness, and previous work has shown these to be related to erosional topography on the underlying unconformable Borden surface (Birch, 1980; Nicholson, 1983; Frankie, 1990). Erosional lows on the post-Borden unconformity were filled with thicker Big Lime carbonates during the subsequent transgression.

Hydrocarbon Production

Oil and natural gas production from the Big Lime is widespread in eastern Kentucky, as shown by the production map to the left. This map shows wells reported as oil or natural gas producers (or both) from the Big Lime. Hydrocarbon traps are predominantly stratigraphic, although some fields correlate with positive structural features, most notably the Rockcastle River Uplift in Clay County. Reservoir rocks include fractured limestone, porous dolostone, porous oolitic limestone, and in limited areas, sandstone. Some of the linear field outlines in Leslie, Perry, and Letcher Counties represent production from a basal dolostone zone in the Big Lime. These linear fields contain thicker Big Lime sections, deposited in erosional channels on the underlying Borden Group surface. Transgressive carbonates filling the channels were preferentially dolomitized to form stratigraphic traps (MacQuown and Pear, 1983; Conrad and others, 1994; Moshier and Stamper, 1994; Tebo and others, 1994). A sandstone and conglomerate unit at the base of the Big Lime in southern Whitley County produces gas in two fields. This clastic unit was interpreted as tidal channel and tidal flat deposits by Vest (2000). A comprehensive review of natural gas production from the Big Lime in the Appalachian Basin, including detailed reservoir data, can be found in Smosna (1996). A petrographic study of Big Lime outcrops and well cuttings in the Pine Mountain Overthrust area was completed by Johanson (1998).

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