



Evaluation of Available Resources of the Middle Kittanning (No. 6) and Lower Kittanning (No. 5) Coal Beds in Ohio

by
Christopher E. Wright
&
Nathan R. Erber

A T H E N S

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ABBREVIATIONS USED IN THIS REPORT

Units of Measure

foot/feet	ft
inch(es)	in
mile(s)	mi
million years ago	m.y.a.

Other

digital elevation model	DEM
geographical information system	GIS
light detection and ranging	LiDAR
mean sea level	m.s.l.

Evaluation of Available Resources of the Middle Kittanning (No. 6) and Lower Kittanning (No. 5) Coal Beds in Ohio

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ABSTRACT

An updated evaluation and estimation of the original, remaining, and available (minable) coal resources for the Middle Kittanning (No. 6) and the Lower Kittanning (No. 5) coal beds of Ohio was completed by the Ohio Department of Natural Resources (ODNR), Division of Geological Survey (Ohio Geological Survey). This is the first published, detailed statewide estimation for the Middle and Lower Kittanning coals for Ohio in more than 60 years. A geographic information system (GIS) was used in the generation of basal structure and thickness isopach maps from existing Ohio Geological Survey data sources. More than 25,000 individual data points were used, with 94 percent being reviewed for both spatial and geological accuracy. Basal structure maps were generated using the Natural Neighbor interpolation technique; a multistep process of kriging and topo-to-raster modeling was used to create thickness isopach maps. Coal tonnages were calculated from the isopach maps and were summarized by county. The original resource tonnage estimates show that there were 19.2 billion short tons of the Middle Kittanning coal and 15.1 billion short tons of the Lower Kittanning coal prior to any mining in Ohio. Approximately 1.8 billion short tons of Middle Kittanning coal and 0.81 billion short tons of Lower Kittanning coal have been mined, leaving 17.4 billion and 14.3 billion short tons of remaining coal resources, respectively. Of the remaining resources, 11.2 billion short tons of deep-minable and 0.7 billion short tons of surface-minable Middle Kittanning coal, and 6.4 billion short tons of deep-minable and 0.6 billion short tons of surface-minable Lower Kittanning coal, are potentially minable. The largest available resources are located in Guernsey and Harrison Counties for the Middle Kittanning coal bed and in Belmont and Noble Counties for the Lower Kittanning coal bed.

INTRODUCTION

Coal is an important natural resource and when mined, provides for energy generation and supports manufacturing, making the coal industry a major contributor to the economy. Ohio ranks thirteenth nationally in coal production with more than 12 million short tons mined in 2016 (Stucker, 2017). Approximately 24 coal beds contain minable resources in Ohio (Brant and DeLong, 1960), of which 12 are presently being mined (Stucker, 2017). Coal mining represents 9 percent of the total value of fuel and non-fuel extractive industries, and 2016 coal sales contributed more than \$500 million to the Ohio economy (Stucker, 2017).

Coal mining in Ohio preceded statehood. Coal deposits were first described as early as the 1740s, with rudimentary mapping in 1752 and the first recorded coal mining occurring in Jefferson County by 1800 (Crowell, 1995). Coal was a major driver of the industrial revolution and helped encourage the growth of the U.S. economy. The use of coal has evolved over time, starting as a heating fuel, to powering locomotives and ships, to the forging of steel. In 2016, more than ninety percent of coal consumed in the United States was used for electrical generation (IER,

2016); in Ohio, fifty-nine percent of the electricity is generated in coal-fired power plants (EIA, 2017).

The Kittanning coals historically have been among the most important coals for mining in the northern Appalachian Basin states of Ohio, Pennsylvania, and West Virginia. In Ohio, the Middle Kittanning (No. 6) coal accounts for the second-highest production tonnages, resulting in more than 1.5 million short tons in 2016 (Stucker, 2017). The largest deposits are found in Guernsey, Harrison, Noble, and Belmont Counties. However, the Lower Kittanning (No. 5) coal records the tenth-highest production tonnages for Ohio, with resulting production exceeding 65,000 short tons in 2016 (Stucker, 2017). Major deposits are in Belmont, Noble, Guernsey, and Jefferson Counties.

Coal production in Ohio has decreased by 50 percent since 2013 (Wolfe and Stucker, 2014; Stucker, 2017). The decrease in coal mining is occurring worldwide and has multiple causes, including decreased demand; a drop in coal prices; increased environmental restrictions; and the development of inexpensive, abundant, cleaner-burning natural gas deposits.

Although the Middle and Lower Kittanning coals are presently mined in Ohio, the extents and quantities of the remaining resources are not precisely known.

The last detailed statewide resource assessments for the Middle Kittanning (fig. 1) and Lower Kittanning beds (fig. 2) were calculated in the 1950s (Brant, 1954, 1956) and republished in 1960 (Brant and DeLong, 1960). It is important for the coal mining industry to know where coal is of mineable thickness so that companies can effectively plan future development. The last statewide resource estimates are more than 60 years old and are not suitable for present-day mine planning. Since the last resource estimates in the 1950s, the Ohio Geological Survey has collected vast quantities of data from active and historical mining operations. Additionally, resource estimation techniques have improved and utilize computer-processing techniques, such as GIS, which enhance the accuracy and speed with which resource estimates are performed. The principal goals of this study were to map and estimate the original and available (minable) tonnages of the Middle and Lower Kittanning coal beds in Ohio.

GENERAL GEOLOGY OF THE KITTANNING COAL ZONE

In Ohio, coal is found only in the eastern third of the state. These coals were deposited during the Pennsylvanian (359–299 million years ago [m.y.a.]) and Permian (299–252 m.y.a.) Periods (Collins, 1979; Cohen and others, 2013). Ohio coal deposits of the Pennsylvanian System consist of the Pottsville, Allegheny, Conemaugh, and Monongahela Groups, while the Permian System consists of the Dunkard Group (fig. 3; Collins, 1979). The Middle and Lower Kittanning coal beds are found within the Pennsylvanian Allegheny Group, which was once referred to as the Lower Coal Measures (Rogers, 1858; White, 1879; Larsen, 1991; Larsen, 2015).

This relatively short, 24 million-year period of Pennsylvanian time exhibited some of the most prolific deposition of coal in Earth's history. Coals were deposited in abundance as a result of expansive, tropical swampy mires and forests, which grew on the edge of shallow seas and up into low-lying fluvial delta plains (Ferm and Cavaroc, 1969; Thomas, 2002). Approximately 67 individual coal beds are named in Ohio (Brant and DeLong, 1960). Ohio's coal-bearing strata reveal repeated cycles of deposition known as *cyclothems* (Weller, 1930; Wanless and Weller, 1932; Larsen, 1991). Cyclothems occurred in response to global sea-level fluctuations caused by repeated freezing and melting cycles of continental glaciers on the supercontinent of Gondwana (Plint and others, 1992; Nadon and Kelly, 2004; van den Belt and others, 2015).

The Pennsylvanian-age rocks in Ohio were deposited on the western edge of the northern Appalachian

Basin, which formed west of the Appalachian Mountains (Rice and Schwietering, 1988; Tewalt and others, 2001). These deposits typically consist of sandstones, siltstones, shales, mudstones, marine and freshwater limestones, clays, and coals (Collins, 1979). Lateral changes in lithology are common, as these rocks were deposited in or near fluctuating deltaic environments (Ferm and Cavaroc, 1969; Ferm and Weisenfluh, 1989). Coals and marine limestones were more laterally persistent, covering extensive areas of the Appalachian Basin (Larsen, 1991; Rice and others, 1994), as these rock types were deposited under more relatively stable conditions. Therefore, they make excellent marker beds for regional correlations.

Both the Middle and Lower Kittanning coal beds were formed in lower and upper delta plain-fluvial environments (Ferm and Cavaroc, 1969; Ferm and Weisenfluh, 1989; Thomas, 2002). Coal depositional environments are classified based on distance from coastal marine settings (Thomas, 2002). As cyclical sea-level fluctuations occurred across Ohio, many different environments were preserved in the rock strata. The Middle and Lower Kittanning coal beds are some of the most laterally persistent coals deposited in Ohio (Ferm and Cavaroc, 1969). Alternatively, in some places periods of non-deposition occasionally occurred, resulting in an absence of coal. Another instance of coal being absent occurred prior to lithification, when an overlying, fluvial-deposited sandstone paleochannel eroded overburden to the level of the coal, partially in some places or entirely in others.

Geological structures, such as folds and faults, are known to influence coal bed structure, but these features can also affect coal bed thickness (Thomas, 2002). Under compressional conditions, coal can become thicker, and under tensional conditions, the coal becomes stretched and thinned or even absent (Thomas, 2002). Structure mapping indicates that several fault and lineament trends, previously identified in the underlying Devonian Berea Sandstone (Solis, 2015), also influence the coal bed structure (Sorrell and Spahr 2016a, 2016b). These features are identifiable by reviewing areas where atypical changes in elevation occur on the structure maps and then determining if they coincide with known structural features. The main features identified are the Cadiz anticline (Griswold, 1902) in Harrison County; the Highlandtown (or Transylvanian) fault zone (Solis, 2015) in Columbiana County; and the Cambridge Cross-Strike Structural Discontinuity (Solis, 2015) in Coshocton, Guernsey, Noble, and Washington Counties, which is the most visible of the three structures (fig. 4). The Cambridge Cross-

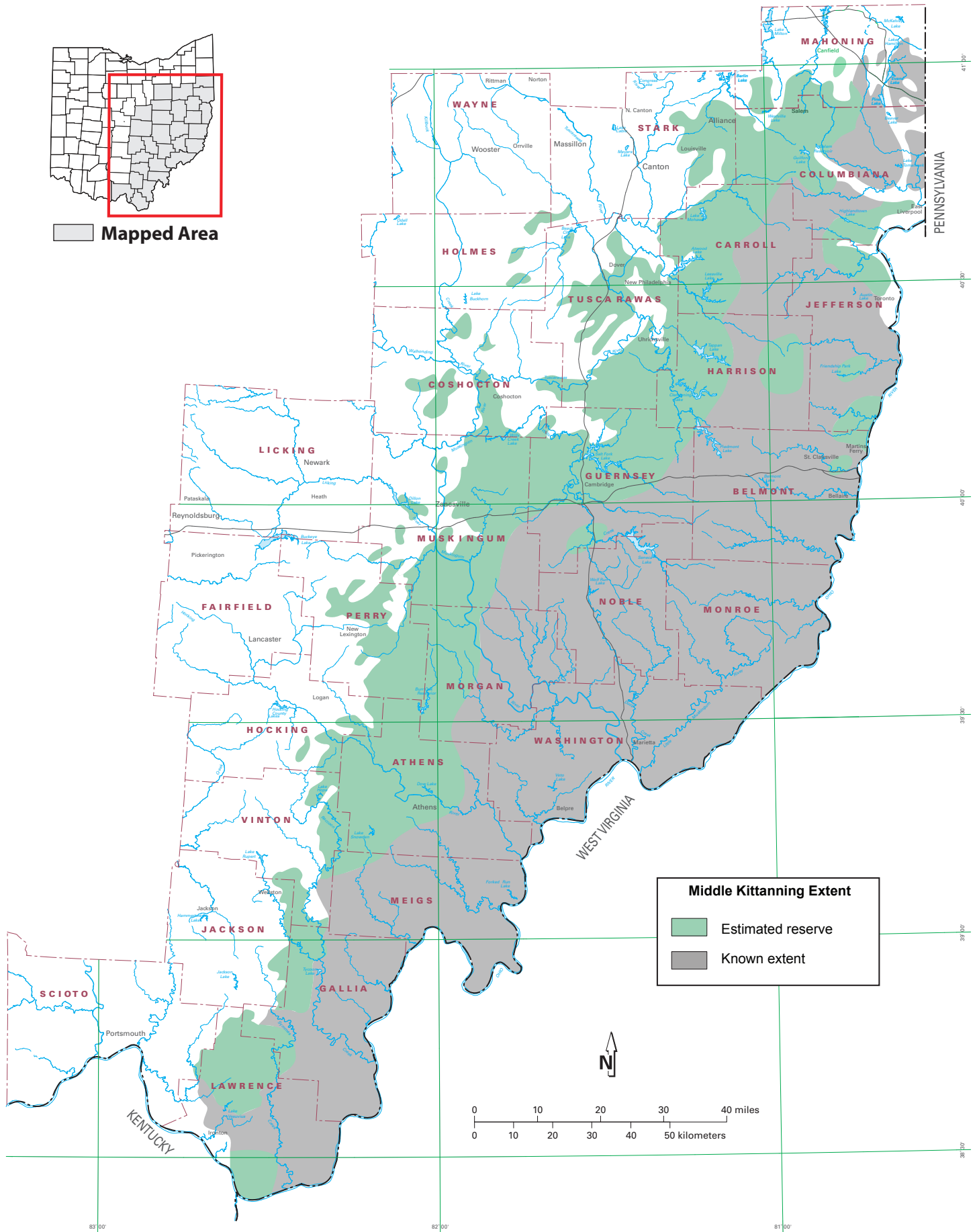


FIGURE 1. Known extent of the Middle Kittanning (No. 6) coal bed in Ohio during the last resource estimate. Modified from Brant and DeLong (1960).

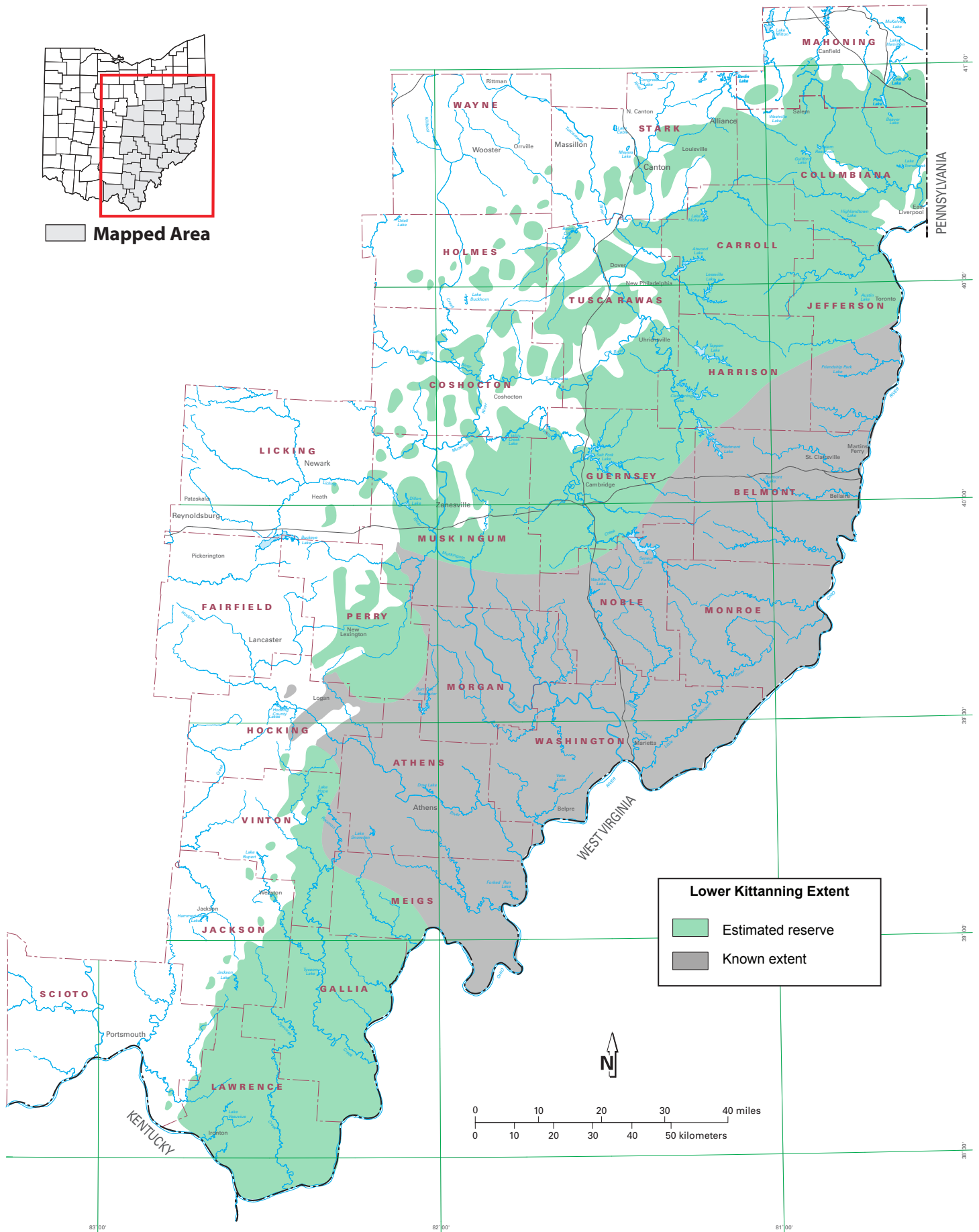


FIGURE 2. Known extent of the Lower Kittanning (No. 5) coal bed in Ohio during the last resource estimate. Modified from Brant and DeLong (1960).

Strike Structural Discontinuity separates the coal deposits in Ohio into a northeastern component and a southwestern component.

Lower Kittanning (No. 5) Coal Bed

The Lower Kittanning coal bed is underlain by approximately 50 ft of mudstone and minor amounts of sandstone and is overlain by approximately 30 ft of mudstone and shale. The areal extent of the Lower Kittanning coal bed is discontinuous in nature across much of Ohio. The typical coal section in this area consists of three benches of coal of similar thickness, separated by two thin mudstone partings. Elsewhere in the state, the Lower Kittanning is composed of just one main bench or two benches of coal separated by a thin mudstone parting.

After the deposition of the Lower Kittanning coal ceased, the area was flooded. In Ohio, the Columbiana shale overlies the Lower Kittanning coal bed (fig. 3) and is identified by its black color and abundant marine fossils. Siderite nodules and ironstone deposits found within the shale make this a useful marker horizon for confirming the identity of the underlying Lower Kittanning coal bed.

Middle Kittanning (No. 6) Coal Bed

The Middle Kittanning coal bed is underlain by approximately 30 ft of mudstone and shale and is overlain by approximately 50 ft of sandstone and shale. The Middle Kittanning coal bed typically is consistent in thickness and areal extent across much of Ohio. The typical coal section consists of a thicker upper bench, a thin mudstone parting, and a thinner lower bench. The thickest Middle Kittanning coal bed intervals are in Athens, Hocking, and Perry Counties. After the Middle Kittanning was deposited, the area was flooded, and this interval is represented by the black, fossiliferous, marine Washingtonville shale (fig. 3).

METHODOLOGY

This study uses standard methodologies developed by the U.S. Geological Survey (USGS) to assess coal resources (Wood and others, 1983; Carter and Gardner, 1989; Eggleston and others, 1990; Carter and others, 2001). The Coal Resource Classification System of the USGS (Wood and others, 1983) defined minimum coal thickness requirements for underground (or deep) mining coal as ≥ 28 in and for surface mining coal as ≥ 14 in. The USGS also defined coal resource reliability categories based on predefined distances from data points; these include Measured (0–0.25 mi), Indicated (0.25–0.75 mi), Inferred (0.75–3 mi), and Hypothetical (beyond 3 mi) (Wood and others, 1983).

Before coal resources could be assessed, a database

was created using various data sources and data types (table 1), including basal coal bed elevations and coal bed thickness data points, for the Middle and Lower Kittanning coal beds. Oil-and-gas wells containing Allegheny-age strata that had been logged with gamma ray and density logs were correlated so that additional coal elevation and thickness data could be added to the database. To better interpolate coal bed thicknesses and elevations for the entirety of Ohio, data was used from neighboring Kentucky and West Virginia.

The data points database was imported into ArcGIS® and interpolated to create maps of basal elevation structure and isopach coal bed thickness for both the Middle and Lower Kittanning coal beds. The isopach maps were used to calculate the original coal resource tonnages, defined as the amount of coal estimated to have been present in the state prior to any mining activity. The remaining resources were calculated by subtracting mined coal areas from the original resource area. The available (minable) resources were calculated by subtracting areas restricted by technological and land-use factors from the remaining resources. Middle and Lower Kittanning coal bed tonnages were calculated and summarized by county.

Data Verification

Overall, 25,168 data points were used in this study, of which 23,559 (94%) were individually reviewed for spatial and vertical accuracy. In total, the Middle Kittanning coal bed had 5,432 thickness points and 21,165 elevation points; the Lower Kittanning coal bed had 3,438 thickness points and 4,401 elevation points. Many individual data points contained thickness and elevation data for both beds. Data points were geospatially verified using GIS and compared to digital elevation model (DEM) surface elevations to confirm that outcrop data points were not positioned at elevations above or below the land surface.

Several techniques were used to verify data accuracy and to correct for potential errors. First, original log files of the data points were reviewed to identify key stratigraphic marker beds. The marker beds of the Upper Freeport, Lower Freeport, Middle Kittanning, and Lower Kittanning coals were correlated across Ohio. Encompassing all four coal beds resulted in greater reliability in the correlations. Additionally, easily identifiable marker beds consisting of fossiliferous shale, limestones, fireclay, conglomerate, and red and green shale beds were used to assist coal bed correlations. Marker bed identification allowed for more reliable correlation of coal beds and provided the ability to compare thickness trends between marker beds, ensuring consistent interval identification between adjacent data points.

Second, residual values from interpolations were examined for data outliers. After the structure or thickness was modeled, data point values with the highest predicted residual errors, calculated by subtracting the observed data point value from the

predicted value, were reviewed. In some cases, data entry or miscorrelation errors were discovered and corrected. If there was no evidence of error, the data was left unchanged. After errors were corrected, structure and thickness interpolations were repeated in this manner until the highest residual error values were either reviewed or corrected.

Third, structure maps and associated data points were reviewed for erroneous elevation changes that did not conform to the geology of the area. Elevation points and interpolated coal structure maps were compared to known structural trends, and when discrepancies occurred, data points were reviewed for error and corrected.

Fourth, modeled raster surfaces for the Middle and Lower Kittanning coal beds were compared to one another to determine if there were places where the Middle Kittanning coal was mistakenly found below the Lower Kittanning or vice versa. Locally, intervals between coal beds are consistent and do not typically change rapidly; however, with greater distances between data points, intervals between coal beds can vary substantially. Structure interpolation did not account for the rock interval between coal beds, and interpolation for each bed was completed independently; therefore, coal beds potentially could intersect underlying or overlying coals where minimal data was available.

Map Creation

Structure map

In mineral resource studies, geologic structure typically is modeled using the top elevation of a geologic unit. Coal resource studies do not typically conform to this convention and instead model structure on the base of the coal bed. The reason for this datum is that the top of the coal bed can be more variable owing to geologic factors, such as rock partings, channel sandstone scouring, and interruption of coal deposition, resulting in a thinner coal bed.

The structure maps for both the Middle and Lower Kittanning coal beds were generated in ArcGIS® using the Natural Neighbor interpolation technique. The Natural Neighbor technique does not interpolate beyond the maximum and minimum data values, nor the areal extent of the data, and therefore cannot infer trends beyond the available data (Sorrell and Spahr, 2016a, 2016b).

Once generated, the structure interpolation was clipped to the state boundary and the coal bed outcrop. The coal bed outcrop is where the modeled plane of the coal bed exits the surface topography and was defined by removing areas of the modeled surface with elevations higher than the DEM.

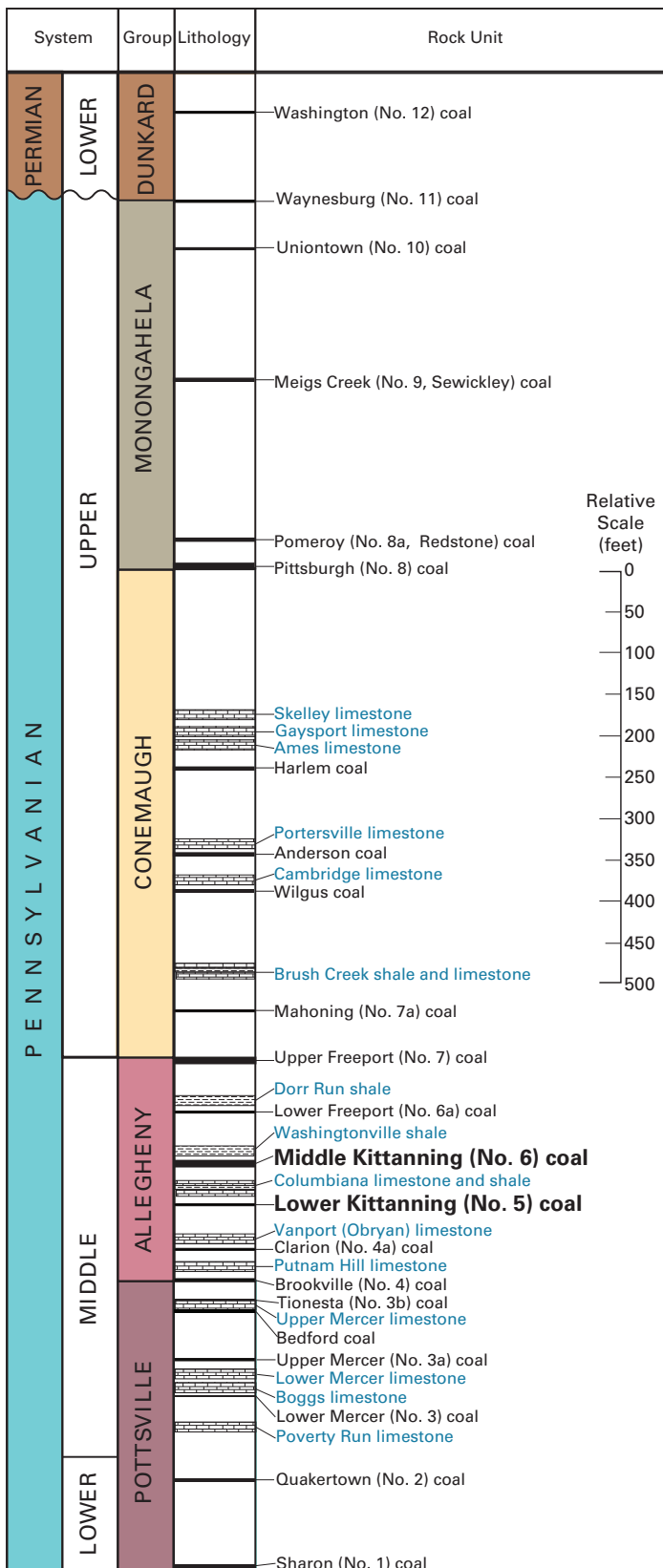


FIGURE 3. Generalized stratigraphic column of the major lithologic units in the Pennsylvanian and Permian Systems in Ohio. Marine units are in blue. Modified from Struble and others (1971).

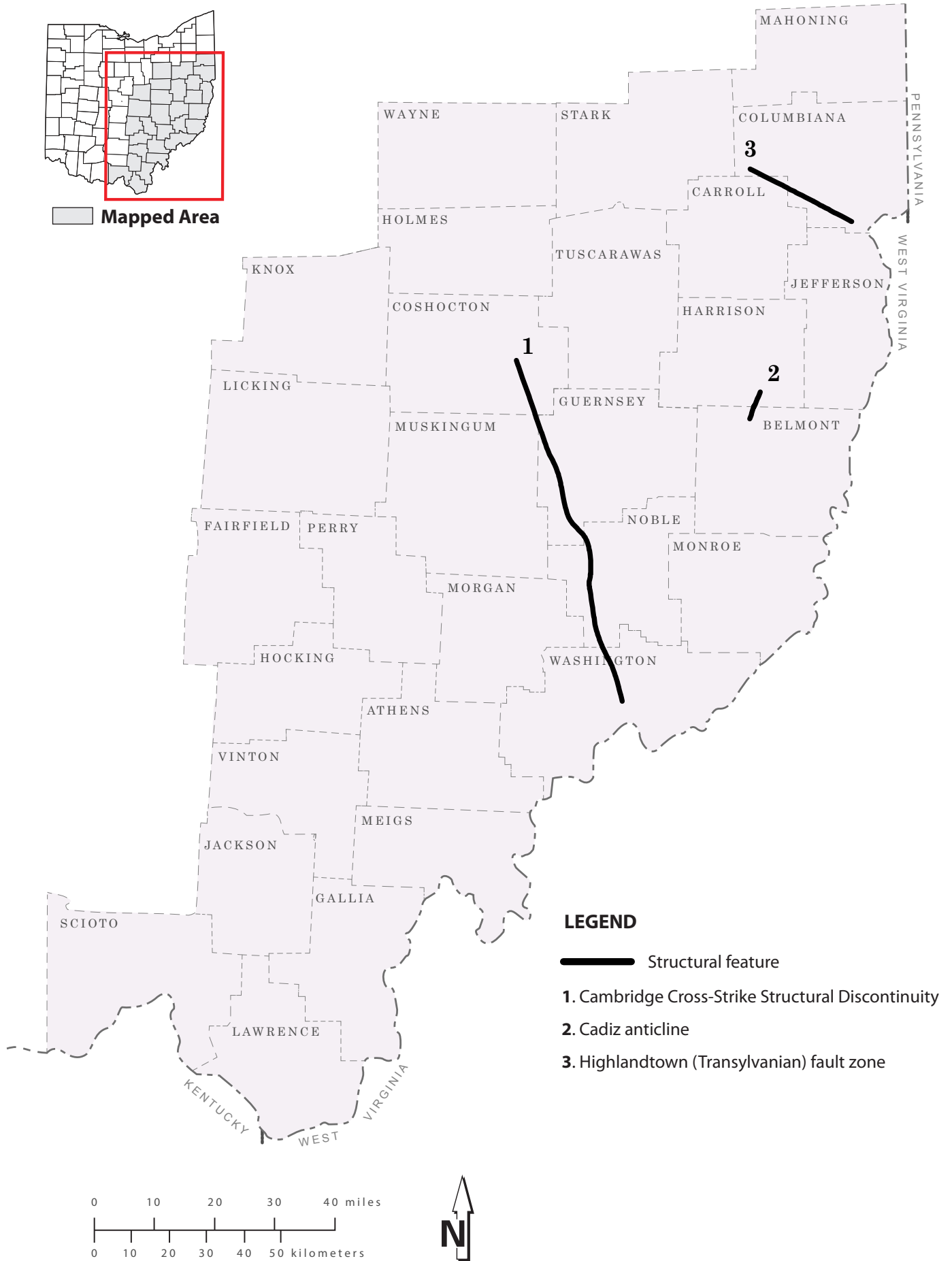


FIGURE 4. Structural features that affect the Middle and Lower Kittanning coal beds in Ohio. Modified from Baranoski (2013).

TABLE 1. Middle and Lower Kittanning coal bed data sources

Source	Type	Notes
USGS	Core logs, measured sections	National Coal Resource Data System (NCRDS) Ohio database (NCRDS, 2017)
Ohio Geological Survey	Core logs, measured sections	Data from published and unpublished Ohio Geological Survey reports
Oil-and-gas wells	Geophysical logs	Oil-and-gas wells, containing Allegheny-age strata (logged for gamma ray and density)
Ohio Department of Transportation (ODOT)	Core logs	Engineering boring logs from ODOT
Coal companies	Core logs, measured sections	Mine permit logs from Ohio Department of Natural Resources, Division of Mineral Resource Management (DMRM)
Abandoned underground mine (AUM) data	Mine elevation, coal thickness	From Ohio Geological Survey work done for the Ohio Mine Subsidence Insurance Underwriting Association (OMSIUA) program, and Office of Surface Mining Reclamation and Enforcement (OSMRE)
Kentucky Geological Survey (KGS)	Core logs	Core hole records downloaded from the KGS Interactive Map Borehole Search website (KGS, 2017)
USGS	Core logs, measured sections	National Coal Resource Data System (NCRDS) West Virginia database (NCRDS, 2017)
West Virginia Geological & Economical Survey (WVGES)	Geophysical logs	Oil-and-gas well records, containing Allegheny-age strata (logged for gamma ray and density), downloaded from WVGES Interactive Oil & Gas Well Header Data Search website (WVGES, 2017)

Original resources

The original resource is the amount of coal that existed prior to mining. Recent resource estimation studies have used ordinary kriging interpolation to estimate coal thickness (Olea and others, 2011; Olea and Luppens, 2014; Sorrell and Spahr, 2016a, 2016b). Ordinary kriging does not honor the original data points and is a smoothing interpolator that does not interpret beyond the data coverage (Childs, 2004). Greater accuracy of the coal thickness modeling was achieved by developing a multistep process so that the original data point values would be honored. In order to model to the full extent of the state boundary in eastern and southern Ohio, thickness and elevation points were added from Kentucky and West Virginia. Data control points were created in the western and northern parts of the mapping area to better define the outcrop of the coal beds. Points were created by projecting the coal thicknesses and elevations from the existing trends of nearby data points, which allowed ArcGIS® to model the beds beyond the last occurrence of data on the edge of the mapping area. Data control points aided in ensuring that interpolations avoided identifying coal in areas beyond where coal was confirmed to exist.

Data spacing was determined by running the average nearest neighbor tool. When the kriging model was completed, the interpolated raster surface with an output cell size of 100 x 100 ft was saved for later use. After it was generated, the modeled surface was contoured in 1-ft intervals and smoothed to yield a

more realistic result. Next, an improved raster was created using the original thickness data points and the smoothed contours, which were clipped to the study boundary. This multistep method generated a more geologically plausible representation of the coal bed thickness compared to ordinary kriging alone. Coal that was considered too thin for mining or classified as hypothetical was removed. Hypothetical resources are not very reliable because of the large distances (> 3 mi) between data points and are excluded from resource classification.

Remaining resources

Remaining resources were determined by removing all areas of previous surface and

underground mining from the original coal resources. Mine maps of both surface mining and underground mining exist in State of Ohio GIS datasets currently managed by the ODNR Division of Mineral Resources Management (DMRM).

Previous mine map data sets from the DMRM and the Ohio Geological Survey consist of outlines from mine maps, locations of mine portals and shafts, or permits indicating where coal was planned to be mined. Areas of historic surface mining, before permitting was required, were delineated by previous DMRM and Ohio Geological Survey researchers utilizing aerial photography, LiDAR, and historic topographic maps. Some underground mines do not have mine maps available; no extrapolation for these areas was made.

For deep-mined areas, regardless of mining method, it was assumed that all coal within the mine was extracted. An additional 200-ft safety buffer was added from the mine perimeter to account for potential problems of mine georeferencing or for mine maps being incomplete and not showing the full mining extent. No buffer was added to previous surface mining, as any new surface mining would be permitted up to where the previous mining ceased. New surface mines would also maintain a 200-ft safety buffer from old deep-mine workings because many old deep mines are filled with water and water pressure can build up in them, leading to dangerous blowouts. Water found in these abandoned mines may contain high concentrations of heavy elements and metals that could be introduced into streams and groundwater, if breached.

After the previously mined areas were removed from the original resources, the remaining resources were split into surface-minable and deep-minable categories. This split was based on the thickness of rock above the coal bed, known as *overburden*, and the total coal thickness. A ratio of the overburden thickness to the total coal thickness is used as a proxy for economic feasibility and was calculated using the model of the coal bed structure, coal thickness, and the surface DEM. Surface mining is not typically performed in areas where the ratio of overburden to coal thickness exceeds 20:1.

Available resources

Available resources are determined by removing areas that are restricted by land use and technological factors from the remaining resources. Commonly,

land-use restrictions affect surface-minable coal, and technological factors most often affect deep-minable coal. Some factors, such as oil-and-gas wells, lakes, and towns, can affect both surface and underground mining.

No single, standard set of restrictions and buffer distances is used for resource estimation studies in the United States. Restrictions are determined on a basin, region, or even state-by-state basis. A list of restrictions and corresponding buffer distances was created (table 2) based on work from similar studies (Wood and others, 1983; Carter and Gardner, 1989; Eggleston and others, 1990; Axon, 1996; Tabet and others, 1999; Carter and others, 2001; Tewalt and others, 2001; Quick and others, 2004, 2005; Sorrell and Spahr, 2016a, 2016b).

TABLE 2. Restrictions to mining and the amount of buffer required for each restriction

Restriction	Buffer (ft)	Notes	Restriction Type		Type of Mining	
			Land-Use	Techno-logical	Surface	Deep
Airports	100		•		•	•
Cemeteries	300		•		•	
Public buildings	300		•		•	
	100	If overburden is >200 ft, no buffer is needed	•			•
National Register of Historic Places	100		•		•	
Towns	300		•		•	•
Lakes and Reservoirs	100		•		•	•
Major streams	100	If overburden is >200 ft, no buffer is needed	•		•	•
Dedicated Scenic River	1,000		•		•	
Wetlands	0		•		•	
State Park/Forest Preserve	300		•		•	
National Park/Forest	0		•		•	
National or State Park/Forest or Preserve	–	If overburden is >200 ft, no buffer is needed	•			•
Oil and Gas wells (actively producing)	150		•		•	•
Inactive oil-and-gas wells	25		•		•	•
Radio towers	100		•		•	
Pipelines	100		•		•	
Power lines	100		•		•	
Railroads (active)	100		•		•	
Public Roads (U.S. Interstates, U.S. Highways, and State Routes)	100		•		•	
Deep-mine barrier pillars	200			•	•	•
Surface-minable minimum coal thickness	–	14 in		•	•	
Deep-minable minimum coal thickness	–	28 in		•		•
Underground over/under mining interval	–	25 ft		•		•
Surface-minable overburden thickness ratio	–	20:1		•	•	
Minimum continuous coal tonnage	–	250,000 short tons		•	•	•
Deep-minable overburden thickness categories	–	<1,000 ft, 1,000–1,500 ft, >1,500 ft		•		•

After the list of mining restrictions and corresponding buffer distances was generated, GIS layers depicting these restrictions were created. Most of the restrictions existed within GIS layers from the State of Ohio databases. Some of the GIS layers that did not exist were created from other sources, such as the USGS National Transportation Dataset (airport restrictions) and the National Parks Service (National Park/Forest and National Register of Historic Places restrictions). Most restrictions required a safety buffer of 100 ft, but others used greater distances, up to 1,000 ft (table 2). Many restrictions used for surface mining are not required for underground mining activities and vice versa. However, some restrictions overlap and are needed for both types of mining but may not require the same buffer distances.

Some restrictions, such as minimum coal thickness, intervals between mined coal beds, and minimum continuous coal tonnage, were created from the thickness and structure models. Areas where coal was below the minimum thickness value were removed from resource estimation. Intervals between mined coal beds were determined from the coal bed structure and thickness models and the previous mining. Coal is removed from resource consideration if it is within a 25-ft proximity above and below areas of previous underground mining. After previously mined areas were removed from the available resources, small or geographically isolated coal deposits were analyzed for their coal tonnages using their modeled thicknesses and acreage. If an area was calculated to contain fewer than 250,000 short tons of coal, it was considered too small (by modern mining standards) to be mined and was removed from resource estimation.

County resource calculations

Quantity of coal was calculated for original resources, remaining resources, and available resources on a county basis using the following formula:

$$Q = S_c \times A_c \times T_c$$

where

Q = Quantity of coal in short tons for the county

S_c = Sum of coal thickness in inches for the county

A_c = Conversion factor for map cell size to acres

T_c = Constant value representing 150 short tons per acre-inch estimate for bituminous coal (Wood and others, 1983)

PREVIOUS STUDIES

Historically, researchers have conducted five statewide resource estimates on the Middle Kittanning coal bed and four on the Lower Kittanning coal bed using various methodologies (table 3). These studies used different standard methodologies of their time and were performed by either the USGS (Clark, 1917) or the Ohio Geological Survey (Ray, 1929; Brant, 1954, 1956) or jointly by both organizations (Slucher, 2001).

RESULTS

Coal thickness, basal structure, and restricted areas were all mapped, and original, remaining, and mined-out resources were all calculated. From the resulting maps, the available surface-minable and deep-minable coal resource maps were generated; these maps are the basis of the statewide resource calculations. The total tonnages in each county for the Middle and Lower Kittanning coals are shown in tables 4 and 5. The breakdown of tonnages for the Middle and Lower Kittanning coals, from the original to remaining and finally available resources, are shown in figures 5 and 6.

Structure Maps

The Middle Kittanning structure map was constructed using 21,165 elevation points, while the Lower Kittanning structure map was created using 4,401 elevation points (plates 1, 2). The disparity in the amount of elevation points is a result of differences in mining and exploration of the two coal beds. The areas of lowest data density are found where the coal beds are buried under thicker overburden, primarily southeast in Lawrence and Gallia Counties. Historically, a lack of thick, minable Middle or Lower Kittanning coal in these areas has led

TABLE 3. Previous original-resource estimation studies of the Kittanning coal zone in Ohio

Source	Agency	Coal bed Studied		Description of Methods
		Middle Kittanning	Lower Kittanning	
Clark (1917)	USGS	•	•	<ul style="list-style-type: none"> • Estimated tonnages in all areas >14 in thick • Included coal 14–28 in thick for deep-minable areas • Used a single average coal thickness per county
Ray (1929)	Ohio Geological Survey	•	•	<ul style="list-style-type: none"> • Only estimated tonnages in areas >32 in thick • Used two regional average coal thickness • Excluded data-poor counties from tonnage estimates • Reported clean-coal tonnages, not in-place tonnages
Brant (1954, 1956)	Ohio Geological Survey	•	•	<ul style="list-style-type: none"> • Estimated tonnages in all areas >14 in thick • Included coal 14–28 in thick for deep-minable areas • Resources calculated on acreages between thickness isolines • Used traditional industrial resource estimation technique • Assigned confidence levels
Brant & Delong (1960)	Ohio Geological Survey	•	•	<ul style="list-style-type: none"> • Repurposed tonnage estimates from Brant (1954, 1956)
Slucher (2001)	Ohio Geological Survey & USGS	•		<ul style="list-style-type: none"> • Used GIS for estimation of resource calculations • Unpublished results

TABLE 4. Total estimation of coal tonnages¹ for the Middle Kittanning (No. 6) coal bed in Ohio, by county and type of availability

County	Original Resources	Remaining Resources	Mined Resources	Surface-Minable			Deep-Minable				Depth of Overburden			
				Remaining Surface-Minable	Technologically Restricted Surface-Minable	Land-Use Restricted Surface-Minable	Available Surface-Minable	Remaining Deep-Minable	Technologically Restricted Deep-Minable	Land-Use Restricted Deep-Minable	Available Deep-Minable	Available Deep-Minable Coal 0-1,000 ft of Overburden	Available Deep-Minable Coal 1,000-1,500 ft of Overburden	Available Deep-Minable Coal >1,500 ft of Overburden
Athens	1,554,083	1,128,719	425,364	76,500	13	51,972	24,514	1,052,219	311,485	74,513	666,221	656,583	9,638	0
Belmont	1,440,149	1,440,149	0	0	0	0	0	1,440,149	321,035	3,329	1,115,783	888,324	227,460	0
Carroll	1,186,290	1,153,441	32,849	56,034	39	18,843	37,153	1,097,407	220,771	3,508	856,127	856,127	0	0
Columbiana	571,396	567,274	4,122	57,492	57	14,561	42,874	509,782	477,364	545	31,872	31,872	0	0
Coshocton	301,977	140,624	161,353	83,826	1,758	10,288	71,780	56,798	13,982	602	42,214	42,214	0	0
Gallia	563,559	560,497	3,062	16,802	21	4,174	12,607	543,695	396,098	6,338	141,259	141,259	0	0
Guernsey	1,586,187	1,573,084	13,103	42,328	26	15,645	26,858	1,530,556	55,304	73,164	1,402,088	1,402,088	0	0
Harrison	1,392,921	1,390,353	2,568	15,123	0	6,967	8,156	1,375,230	20,327	20,327	1,229,249	1,229,249	0	0
Hocking	209,094	81,017	128,077	45,594	568	44,853	173	35,423	2,951	31,673	799	799	0	0
Holmes	27,267	17,382	9,885	15,650	616	1,078	13,956	1,733	1,531	2	199	199	0	0
Jackson	182,198	138,968	43,229	42,869	690	9,934	32,246	96,099	49,928	2,969	43,203	43,203	0	0
Jefferson	1,052,550	1,051,548	1,003	3,489	9	2,177	1,302	1,048,059	345,978	6,778	695,302	695,277	25	0
Lawrence	683,352	650,907	32,445	62,936	726	50,136	12,074	587,971	298,833	88,513	200,624	200,624	0	0
Madison	87,138	81,924	5,214	40,380	35	5,544	34,801	41,544	37,150	57	4,337	4,337	0	0
Meigs	79,337	79,337	0	0	0	0	0	79,337	75,464	62	3,810	2,458	1,352	0
Monroe	1,315,923	1,315,923	0	0	0	0	0	1,315,923	410,552	18,927	886,442	379,199	494,337	12,906
Morgan	1,325,801	1,300,295	25,506	1,161	0	99	1,062	1,299,134	231,033	37,966	1,030,134	1,030,134	0	0
Muskingum	1,408,066	1,264,941	143,124	138,829	1,330	21,158	116,340	1,126,112	5,596	34,978	1,085,538	1,085,538	0	0
Noble	1,333,202	1,332,132	1,070	0	0	0	0	1,332,132	183,266	17,467	1,131,398	1,131,351	48	0
Perry	767,920	317,843	450,077	123,666	663	80,515	42,489	194,177	12,142	94,474	87,561	87,561	0	0
Scioto	822	509	313	501	100	303	97	9	9	0	0	0	0	0
Stark	178,218	146,800	31,417	71,631	257	13,489	57,885	75,170	36,905	1,073	37,192	37,192	0	0
Tuscarawas	950,780	651,615	299,166	143,141	695	18,121	124,325	508,174	68,789	10,685	429,000	429,000	0	0
Vinton	234,507	208,066	26,442	50,887	503	29,316	21,068	157,178	112,920	27,229	17,029	17,029	0	0
Washington	767,327	767,327	0	0	0	0	0	767,327	673,953	4,051	89,323	55,957	33,366	0
Wayne	69	36	34	32	0	14	18	4	4	0	0	0	0	0
Ohio Total²	19,200,135	17,360,712	1,839,423	1,089,071	8,106	399,186	681,779	16,271,641	4,468,694	576,229	11,226,706	10,447,575	766,225	12,906

¹Thousands of short tons.

²Any tally inconsistencies are due to rounding of tonnages to the nearest ton.

to less drill-hole exploration. While fewer core holes also are found in deeper parts of the Appalachian Basin, such as in Washington, Monroe, and Belmont Counties, there are greater numbers of oil-and-gas wells.

The Middle Kittanning coal underlies 26 counties, and the Lower Kittanning underlies 27 counties in Ohio. Elevations for the Middle Kittanning coal bed vary from -423 to 1,368 ft above m.s.l., and elevations for the Lower Kittanning vary from -453 to 1,348 ft above m.s.l. Coal bed elevations generally progress in an orderly pattern across the state. The highest or positive elevations are found in the north and west, along the coal bed outcrop, and the lowest or negative values are found in the east and south along the Ohio River in Meigs, Monroe, and Washington Counties. In Ohio, coal-bearing strata generally dip at 15-20 ft per mi to the southeast. The rocks northeast of the Cambridge Cross-Strike Structural Discontinuity dip at 15 ft per mi, and southwest of the discontinuity the rocks dip at 20 ft per mi.

Original Resources

The original resources of the Middle Kittanning coal and the original resources of the Lower Kittanning coal were calculated using 5,432 and 3,438 thickness points, respectively (plates 3, 4). The data points are clustered in areas along or near the coal bed outcrop, in areas of previous mining, and in areas of abundant oil-and-gas well development during the 1980s and 1990s. In areas not described above, the data points are much sparser and more widely distributed.

Prior to mining, approximately 19.2 billion short tons of Middle Kittanning coal and 15.1 billion short tons of Lower Kittanning coal existed in Ohio. The maximum interpolated thickness of the

TABLE 5. Total estimation of coal tonnages for the Lower Kittanning (No. 5) coal bed in Ohio, by county and type of availability

County	Original Resources				Mined Resources				Surface-Minable				Deep-Minable				Depth of Overburden			
	Original Resources	Remaining Resources	Mined Resources	Remaining Surface-Minable	Technologically Restricted Surface-Minable	Land-Use Restricted Surface-Minable	Available Surface-Minable	Remaining Deep-Minable	Technologically Restricted Deep-Minable	Land-Use Restricted Deep-Minable	Available Deep-Minable	Available Deep-Minable Coal 0-1,000 ft of Overburden	Available Deep-Minable Coal 1,000-1,500 ft of Overburden	Available Deep-Minable Coal >1,500 ft of Overburden	Available Deep-Minable Coal 0-1,000 ft of Overburden	Available Deep-Minable Coal 1,000-1,500 ft of Overburden	Available Deep-Minable Coal >1,500 ft of Overburden			
Athens	584,246	581,084	3,162	4,270	2	4,145	123	576,814	510,668	1,218	64,928	55,425	9,503	0	55,425	9,503	0			
Belmont	1,254,960	1,254,960	0	0	0	0	0	1,254,960	457,509	2,177	795,273	656,594	138,679	0	656,594	138,679	0			
Carroll	881,555	855,529	26,026	29,244	17	8,937	20,291	826,285	386,757	9,832	429,695	429,695	0	0	429,695	0	0			
Columbiana	1,019,246	997,899	21,347	105,411	44	36,492	68,874	892,489	472,735	7,090	412,663	412,663	0	0	412,663	0	0			
Coshocton	183,581	108,953	74,628	50,812	1,154	3,711	45,947	58,141	54,454	66	3,621	3,621	0	0	3,621	0	0			
Gallia	505,030	498,310	6,720	7,535	0	5,237	2,298	490,775	371,749	12,582	106,445	106,445	0	0	106,445	0	0			
Guernsey	1,037,206	1,028,826	8,379	23,556	41	10,111	13,404	1,005,270	382,860	25,714	596,695	596,695	0	0	596,695	0	0			
Harrison	818,165	817,920	245	3,065	0	919	2,146	814,855	374,909	3,876	436,069	436,069	0	0	436,069	0	0			
Hocking	58,899	44,753	14,145	13,635	488	12,437	710	31,118	30,787	331	0	0	0	0	0	0	0			
Holmes	71,090	54,528	16,561	43,577	468	2,917	40,192	10,951	7,096	76	3,779	3,779	0	0	3,779	0	0			
Jackson	251,957	177,471	74,486	81,724	1,081	12,606	68,037	95,747	45,811	2,762	47,173	47,173	0	0	47,173	0	0			
Jefferson	988,642	987,286	1,356	4,951	38	3,324	1,589	982,335	384,273	6,519	591,543	591,425	117	0	591,425	117	0			
Lawrence	349,604	333,789	15,814	26,325	242	20,788	5,295	307,464	251,192	29,534	26,737	26,737	0	0	26,737	0	0			
Mahoning	258,497	235,525	22,972	116,084	47	20,046	95,991	119,440	32,286	1,098	86,056	86,056	0	0	86,056	0	0			
Meigs	815,390	688,083	127,307	4	0	1	3	688,078	289,594	5,762	392,722	295,401	97,320	0	295,401	97,320	0			
Monroe	860,359	860,359	0	0	0	0	0	860,359	554,107	8,436	297,815	130,482	167,333	0	130,482	167,333	0			
Morgan	678,686	678,686	0	54	0	16	39	678,632	413,040	3,917	261,674	261,595	79	0	261,595	79	0			
Muskingum	729,238	701,377	27,861	45,758	379	6,682	38,697	655,619	284,106	8,905	362,608	362,608	0	0	362,608	0	0			
Noble	1,127,504	1,127,504	0	0	0	0	0	1,127,504	359,540	13,509	754,454	749,332	5,122	0	749,332	5,122	0			
Perry	219,034	146,531	72,503	51,966	583	17,505	33,878	94,565	78,060	2,125	14,380	14,380	0	0	14,380	0	0			
Scioto	5,676	5,196	480	5,151	374	3,878	899	45	27	18	0	0	0	0	0	0	0			
Stark	208,535	158,133	50,402	57,746	251	14,303	41,192	102,387	90,675	1,142	50,570	50,570	0	0	50,570	0	0			
Tuscarawas	608,362	471,031	137,331	92,899	714	12,188	79,997	378,132	300,139	1,351	75,641	75,641	0	0	75,641	0	0			
Vinton	481,551	377,619	103,932	87,428	424	44,553	42,450	290,191	80,792	51,715	157,684	157,684	0	0	157,684	0	0			
Washington	1,107,643	1,107,643	0	0	0	0	0	1,107,643	692,521	14,921	400,200	198,392	201,809	0	198,392	201,809	0			
Wayne	3,871	3,221	650	3,019	5	194	2,820	202	90	3	110	110	0	0	110	0	0			
Ohio Total²	15,108,526	14,302,218	806,308	852,215	6,352	240,990	604,873	13,450,003	6,866,775	214,679	6,368,536	5,748,573	619,962	0	5,748,573	619,962	0			

¹Thousands of short tons.

²Any tally inconsistencies are due to rounding of tonnages to the nearest ton.

Middle Kittanning was 152 in, while the Lower Kittanning maximum interpolated thickness was 89 in. In general, these maximum thicknesses were localized and did not extend over large areas.

Remaining Resources

Approximately 9.5 percent of the Middle Kittanning coal bed has been mined, leaving an estimated 17.4 billion short tons remaining (fig. 5, plate 5). Of the remaining Middle Kittanning resources, 16.3 billion short tons are deep-minable and 1.1 billion short tons are surface-minable. Guernsey County has the largest amount of remaining deep-minable Middle Kittanning coal with 1.4 billion short tons. Tuscarawas County has the highest tonnage of remaining surface-minable Middle Kittanning coal with 124 million short tons.

Approximately 5.3 percent of the Lower Kittanning coal bed has been mined, leaving an estimated 14.3 billion short tons remaining (fig. 6, plate 6). Of the remaining Lower Kittanning resources, 13.5 billion short tons are deep-minable and 806 million short tons are surface-minable. Belmont County has the largest amount of remaining deep-minable Lower Kittanning coal with 1.3 billion short tons. Mahoning County has the highest tonnage of remaining surface-minable Lower Kittanning coal with 116 million short tons.

Available Resources

Available resources represent the amount of coal that is technically feasible to be mined after areas that are restricted to mining are removed. Approximately 11.9 billion short tons of the Middle Kittanning coal (fig. 5) and 7.0 billion short tons of Lower Kittanning coal (fig. 6) are available for mining.

Middle Kittanning

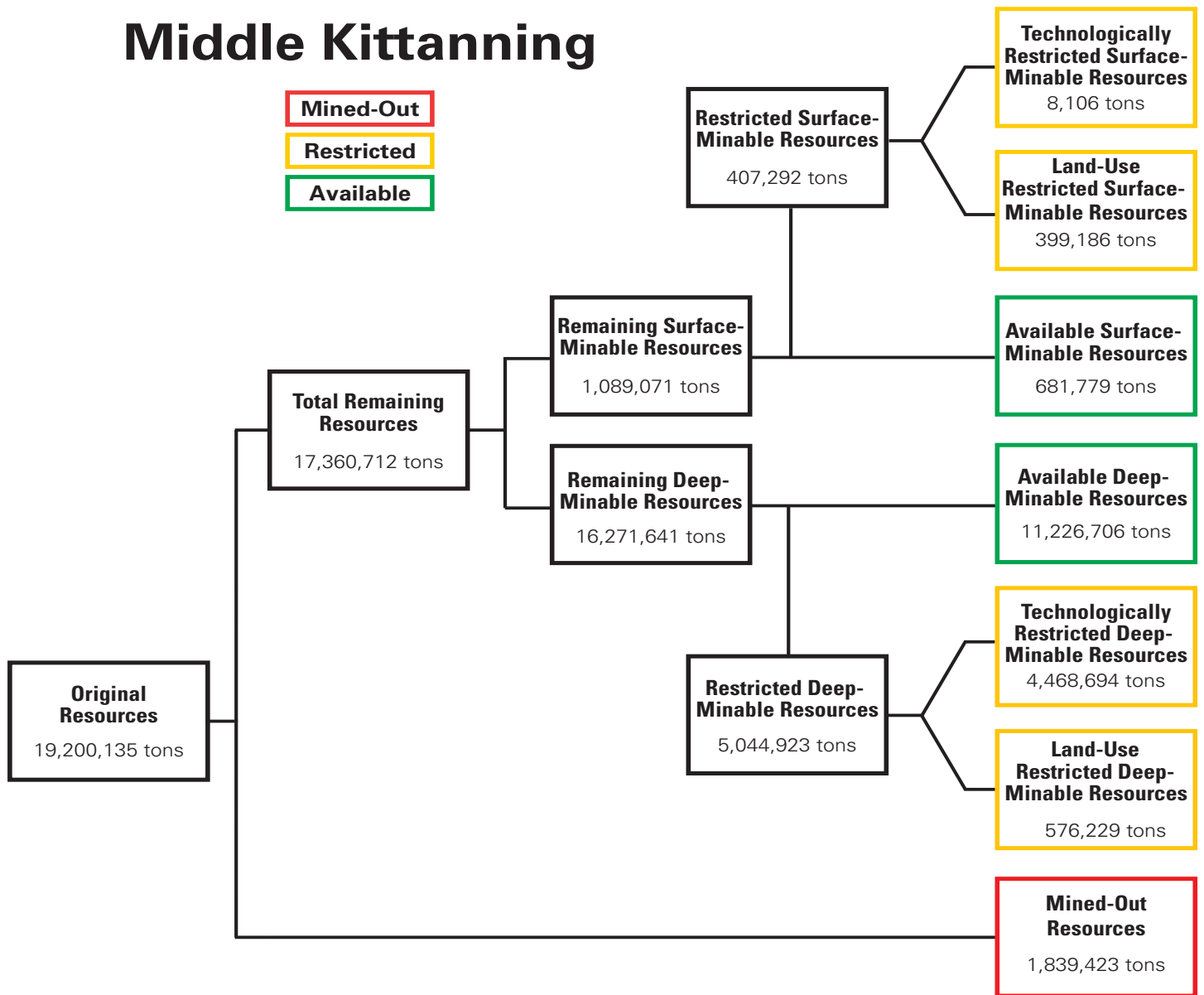


FIGURE 5. Summary of the estimation of the coal resources (thousands of short tons) in the Middle Kittanning (No. 6) coal bed in Ohio.

Surface-minable coal

Applying mining restrictions to the remaining resources yields the available surface-minable coal for the Middle and Lower Kittanning coal beds (plates 7, 8). Of the 1.1 billion short tons of remaining surface-minable Middle Kittanning resources, 407 million short tons are excluded because of restrictions, leaving 682 million short tons of surface-minable coal. Tuscarawas County has the largest available surface-minable Middle Kittanning resources with 124 million short tons. Of the 852 million short tons of remaining surface-minable Lower Kittanning resources, 247 million short tons are excluded because of restrictions, leaving 605 million short tons of surface-minable coal. Mahoning County has the largest available surface-minable Lower Kittanning resources with 96 million short tons.

Deep-minable coal

Applying mining restrictions to the remaining resources yields the available deep-minable coal for the Middle and Lower Kittanning coal beds (plates 9, 10). Of the 16.3 billion short tons of remaining deep-minable Middle Kittanning resources, 5.0 billion short tons are excluded because of restrictions, leaving 11.2 billion short tons of potentially deep-minable coal. Guernsey County has the largest available deep-minable Middle Kittanning resources with 1.4 billion short tons. Of the 13.4 billion short tons of remaining deep-minable Lower Kittanning resources, 7.1 billion short tons are excluded because of restrictions, leaving 6.4 billion short tons of deep-minable coal. Belmont County has the largest available deep-minable Lower Kittanning resources with 795 million short tons.

Lower Kittanning

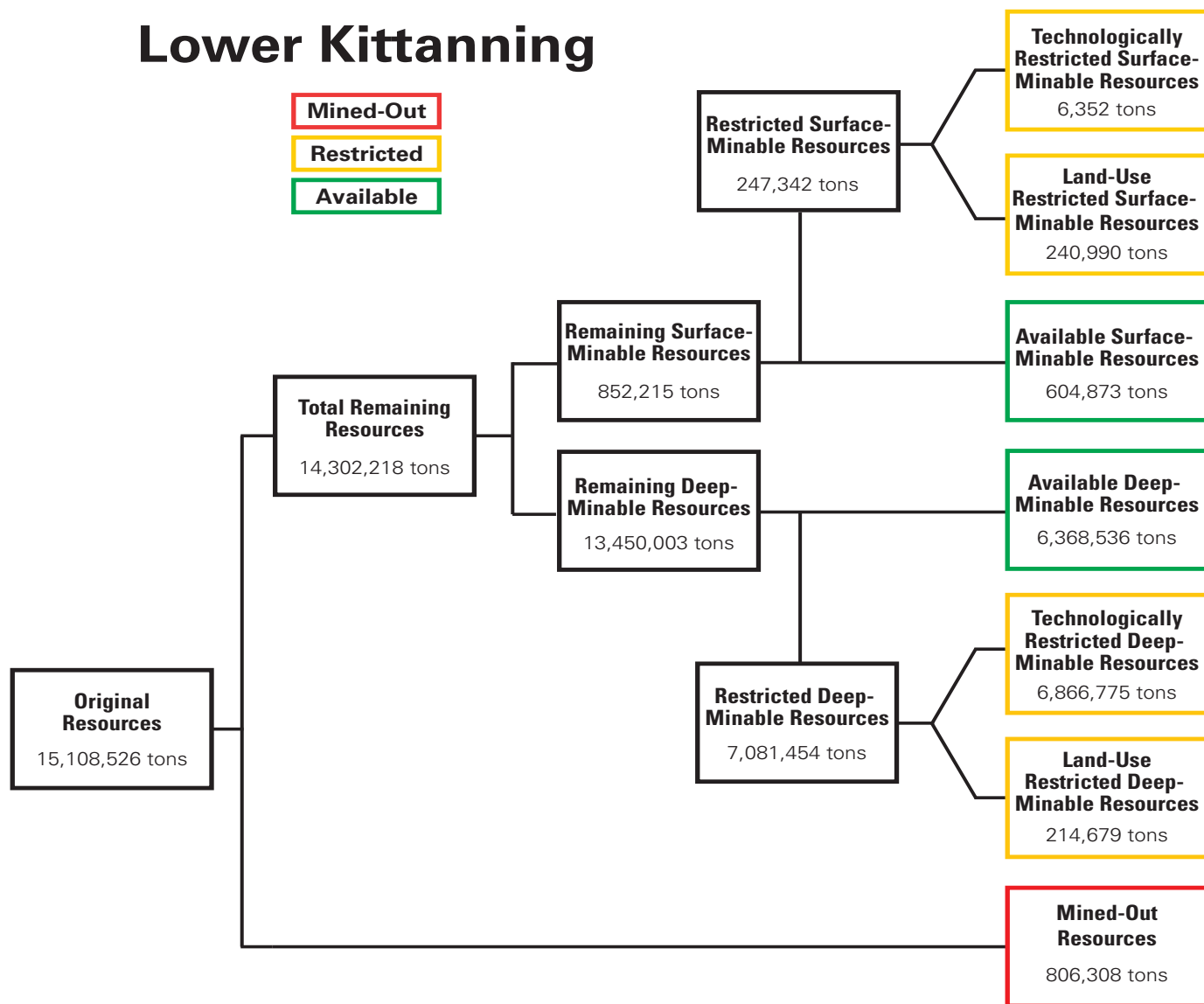


FIGURE 6. Summary of the estimation of the coal resources (thousands of short tons) in the Lower Kittanning (No. 5) coal bed in Ohio.

DISCUSSION

The majority of the available surface-minable and deep-minable resources for both coals are found within the Indicated and Inferred categories (table 6). For a detailed breakdown by county of the total tonnages in each reliability category, see appendices A1–A6. Coal deposits within the Hypothetical category are deemed speculative and are not considered in this resource estimation. There is an increased likelihood for coal bed miscorrelation within the Hypothetical category because these coal tonnages are located in areas of lower data density. Additional data collection in Inferred and Hypothetical areas could increase overall reliability by shifting portions of currently estimated coal tonnages into higher reliability categories.

The possibility exists for additional coal resource tonnage in the poorly explored areas with higher overburden (plates 11, 12); potential areas of interest are the southernmost counties along the Ohio River. These areas have not been well explored by core holes or oil-and-gas wells that include the coal-bearing intervals.

Large portions of the remaining resources are removed from the available resources because of

TABLE 6. Resource confidence level categories and percentage of resource estimate

Reliability Category	Distance from Data Point	Percentage of Middle Kittanning		Percentage of Lower Kittanning	
		Available Surface-Minable Resources	Available Deep-Minable Resources	Available Surface-Minable Resources	Available Deep-Minable Resources
Measured	0–0.25 mile	17.89	7.23	13.10	6.06
Indicated	0.25–0.75 mile	43.31	26.72	37.17	27.24
Inferred	0.75–3 miles	38.8	66.05	49.72	66.70
Hypothetical*	>3 miles	–	–	–	–

*Hypothetical coal not estimated in this resource estimate.

restriction factors. The primary restriction factors for surface mining are land-use restrictions, many of which are owing to environmental regulations and public safety. The primary restriction factor for underground mining is a coal bed thickness of less than 28 in. Equipment restrictions and dilution of coal with incidentally mined rock material makes mining coal below 28 in uneconomic.

Comparison to Previous Works

In previous Middle and Lower Kittanning resource estimation studies, the only directly comparable coal tonnages are those of the original resources category (tables 7, 8). The estimation of original resources in the current study is higher than most of the previous resource estimations for the Middle and Lower Kittanning coal beds. However, the current tonnage estimations are most similar to the tonnages calculated in the resource estimations performed by Clark (1917) and Slucher (2001) (tables 7, 8). The primary discrepancies in tonnage estimates likely is owing to the differences in resource calculation methods and an increase in data availability for eastern Ohio.

Clark’s (1917) estimation identified higher coal tonnages for the Middle Kittanning bed and lower tonnages for the Lower Kittanning bed when compared with the current study. This is likely because of the way he averaged coal thicknesses for each county and his inclusion of coal in deep-minable areas below currently minable limits. Ray’s (1929) estimation identified significantly lower tonnages than any of the other studies, which was likely caused by only estimating coal tonnages in areas exceeding 32 in thick. Ray (1929) also excluded from his estimation those counties where data was not readily available, and he used two average coal thicknesses for the

entire state. Additionally, Ray (1929) did not calculate the *in situ* coal tonnages as the other studies did, but instead he calculated the clean-coal tons, which are representative of the final mined product. Brant’s (1954, 1956) estimations used traditional industry methodologies, which identified lower coal tonnages than the current study. As with the Clark (1917) study, Brant (1954, 1956) included coal below currently minable limits in his deep-minable estimations; however, the differences in resource calculation methods of Clark and Brant yielded much lower tonnage estimates. Brant’s (1954, 1956) estimations are likely lower than the current estimates because of the addition of 60 years of exploration data (Struble and others, 1971), which allowed for the identification of previously undiscovered resources. Slucher’s (2001) resource estimate for the Middle Kittanning coal bed resulted in slightly higher tonnages than the current study. The techniques used by Slucher (2001) were similar to those of the current study; however, a direct comparison is not possible because the detailed results of his work were never published.

Uncertainty

Thin or absent coals present problems for consistent correlations. Coal bed miscorrelations are more likely to occur in areas of thin coal or limited data. Statewide studies of this nature differ from smaller-scale studies of individual quadrangles, which generally review all coal beds present instead of selected beds. Concurrently correlating all coal beds across an area offers less potential for coal bed miscorrelations.

Changing depositional environments present when the coals formed have resulted in differences in characteristics of the coal beds and associated rock interburden across the state (Ferm and Cavaroc, 1969). These shifting depositional environments have caused correlation difficulties, resulting in the use of local coal bed names in different areas of the state (Larsen, 1991, 2015). The Middle Kittanning, Lower Kittanning, and Clarion coal beds were found to be frequently confused with one another in some southern-Ohio areas, such as in Lawrence County, where the Lower Kittanning coal is locally called the Clarion coal.

The degree of correlation uncertainty can be expressed several ways through a data reliability classification. Some recent studies (Olea and others, 2011; Olea and Luppens, 2014)

TABLE 7. Middle Kittanning (No. 6) original resource study comparison

Resource Study	Project Source	Tonnage ¹ Estimate	Tonnage ¹ Difference (from this study)
Wright and Erber (2018)	Ohio Geological Survey	19,200,135	–
Slucher (2001)	Ohio Geological Survey / USGS	21,200,000	–1,999,865
Brant (1956)	Ohio Geological Survey	9,783,598	9,416,537
Ray (1929)	Ohio Geological Survey	3,729,600	15,470,535
Clark (1917)	USGS	22,926,000	–3,725,865

¹Thousands of short tons.

TABLE 8. Lower Kittanning (No. 5) original resource study comparison

Resource Study	Project Source	Tonnage ¹ Estimate	Tonnage ¹ Difference (from this study)
Wright and Erber (2018)	Ohio Geological Survey	15,108,526	–
Brant (1954)	Ohio Geological Survey	9,913,989	5,194,537
Ray (1929)	Ohio Geological Survey	439,296	14,669,230
Clark (1917)	USGS	14,674,000	434,526

¹Thousands of short tons.

have recommended discontinuing the use of the current USGS distance-based reliability classification and instead have opted for sequential Gaussian simulation to statistically model reliability percentiles. Gaussian simulation performs up to 100 equally probable, ordinary kriging interpolation iterations of coal thickness, which are referred to as realizations. This method was used for the Ohio Geological Survey resource estimations of the Lower Freeport and Pittsburgh coal beds (Sorrell and Spahr, 2016a, 2016b). Even though the sequential Gaussian simulation method has the potential for greater accuracy than distance-based reliability classification, it is not widely accepted in industry practice and reporting standards. Consequently, distance-based reliability classifications were chosen for use in this study so that calculation and reporting methodologies would be more beneficial for industry applications.

CONCLUSIONS

This evaluation is the first detailed, published resource estimation in Ohio for the Middle and Lower Kittanning coal beds in more than 60 years. Because of exploration and mining activities since the 1950s, more coal thickness and elevation data are available than during the previous estimates. These data have increased the reported coal resources, when compared to the majority of past estimates, by adding new resource areas that were previously unknown. The available resources for the Middle Kittanning coal were estimated at 11.9 billion short tons, and the Lower Kittanning was estimated to have 7 billion short tons of available resources.

The original coal resource tonnage estimate was approximately 19.2 billion short tons for the Middle Kittanning and 15.1 billion short tons for the Lower Kittanning. After mining and restrictions are applied, 7.3 billion short tons of Middle Kittanning coal and 8.1 billion short tons of Lower Kittanning coal were removed. The largest resources are located in Guernsey and Harrison Counties for the Middle Kittanning coal bed and in Belmont and Noble Counties for the Lower Kittanning coal bed.

This study has shown that large quantities of available surface-minable and deep-minable coal resources exist in the Middle and Lower Kittanning coal beds in Ohio. These coals will likely remain two of the most important coal resources in Ohio for the foreseeable future.

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TABLE A.1. Total estimation of Measured coal tonnages¹ for the Middle Kittanning (No. 6) coal bed in Ohio, by county and type of availability

County	Original Resources	Remaining Resources	Mined Resources	Surface-Minable				Deep-Minable				Depth of Overburden		
				Remaining Surface-Minable	Technologically Restricted Surface-Minable	Land-Use Restricted Surface-Minable	Available Surface-Minable	Remaining Deep-Minable	Technologically Restricted Deep-Minable	Land-Use Restricted Deep-Minable	Available Deep-Minable	Available Deep-Minable Coal 0-1,000 ft of Overburden	Available Deep-Minable Coal 1,000-1,500 ft of Overburden	Available Deep-Minable Coal >1,500 ft of Overburden
Athens	352,884	183,749	169,135	32,238	8	21,792	10,438	151,511	13,080	20,838	117,593	117,538	55	0
Belmont	36,779	36,779	0	0	0	0	0	36,779	8,049	205	28,524	25,185	3,339	0
Carrill	129,321	118,309	11,012	5,281	7	1,707	3,568	113,027	6,525	2,322	104,180	104,180	0	0
Columbiana	22,492	21,634	858	4,646	2	1,142	3,502	16,988	13,719	56	3,213	3,213	0	0
Coshocton	72,919	23,444	49,475	14,349	129	1,622	12,599	9,095	3,083	61	5,951	5,951	0	0
Gallia	20,534	20,210	325	4,289	0	694	3,595	15,920	6,266	778	8,876	8,876	0	0
Guernsey	43,982	39,349	4,633	2,268	6	585	1,677	37,081	1,708	2,665	32,707	32,707	0	0
Harrison	144,930	143,474	1,456	791	0	431	360	142,683	16,117	1,489	125,077	125,077	0	0
Hocking	66,715	18,420	48,296	9,636	50	9,585	1	8,784	1,403	7,337	45	45	0	0
Holmes	7,072	3,681	3,391	3,318	142	332	2,844	363	361	2	0	0	0	0
Jackson	39,534	23,959	15,575	11,163	49	2,841	8,273	12,795	8,332	534	3,929	3,929	0	0
Jefferson	68,053	67,395	658	1,028	3	699	326	66,367	20,343	388	45,636	45,636	0	0
Lawrence	44,820	37,711	7,109	10,735	108	8,299	2,328	26,976	11,137	8,392	7,446	7,446	0	0
Mahoning	7,188	6,563	625	2,880	3	439	2,438	3,684	3,292	0	391	391	0	0
Meigs	8,204	8,204	0	0	0	0	0	8,204	7,155	40	1,009	603	406	0
Monroe	75,184	75,184	0	0	0	0	0	75,184	16,689	2,070	56,425	35,555	20,434	436
Morgan	117,700	114,561	3,139	262	0	21	240	114,299	7,545	6,726	100,028	100,028	0	0
Muskingum	126,616	77,171	49,445	25,803	248	2,918	22,637	51,367	2,181	1,263	47,924	47,924	0	0
Noble	45,152	44,946	206	0	0	0	0	44,946	11,581	1,093	32,272	32,272	0	0
Perry	205,650	91,384	114,265	38,160	175	24,307	13,678	53,225	6,128	22,117	24,980	24,980	0	0
Scioto	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stark	21,449	12,316	9,134	7,272	75	2,807	4,391	5,043	1,353	83	3,608	3,608	0	0
Tuscarawas	166,466	82,950	83,516	27,742	60	3,534	24,147	55,208	8,697	717	45,793	45,793	0	0
Vinton	42,695	25,276	17,419	9,525	53	4,554	4,918	15,751	7,838	3,772	4,140	4,140	0	0
Washington	61,737	61,737	0	0	0	0	0	61,737	49,246	745	11,746	7,971	3,775	0
Wayne	69	36	34	32	0	14	18	4	4	0	0	0	0	0
Ohio Total²	1,928,142	1,338,438	589,704	211,417	1,117	88,322	121,979	1,127,021	231,836	83,692	811,492	783,046	28,010	436

¹Thousands of short tons.

²Any tally inconsistencies are due to rounding of tonnages to the nearest ton.

TABLE A2. Total estimation of Indicated coal tonnages¹ for the Middle Kittanning (No. 6) coal bed in Ohio, by county and type of availability

County	Original Resources	Remaining Resources	Mined Resources	Surface-Minable				Deep-Minable				Depth of Overburden		
				Remaining Surface-Minable	Technologically Restricted Surface-Minable	Land-Use Restricted Surface-Minable	Available Surface-Minable	Remaining Deep-Minable	Technologically Restricted Deep-Minable	Land-Use Restricted Deep-Minable	Available Deep-Minable	Available Deep-Minable Coal 0-1,000 ft of Overburden	Available Deep-Minable Coal 1,000-1,500 ft of Overburden	Available Deep-Minable Coal >1,500 ft of Overburden
Athens	617,913	415,169	202,744	37,097	5	25,111	11,980	378,073	61,207	34,501	282,366	280,395	1,970	0
Belmont	220,091	220,091	0	0	0	0	0	220,091	49,032	802	170,257	143,408	26,848	0
Carroll	468,610	449,164	19,446	23,520	28	8,491	15,001	425,643	41,295	6,930	377,418	377,418	0	0
Columbiana	116,930	115,490	1,440	13,718	2	4,404	9,312	101,772	87,345	257	14,170	14,170	0	0
Coshocton	150,798	72,041	78,757	41,566	784	4,776	36,005	30,476	7,724	350	22,402	22,402	0	0
Gallia	95,738	95,255	483	8,279	21	2,270	5,988	86,976	36,406	1,603	48,967	48,967	0	0
Guernsey	269,329	263,351	5,978	8,848	4	1,438	7,407	254,503	11,360	12,398	230,744	230,744	0	0
Harrison	422,963	421,900	1,063	5,426	0	2,251	3,175	416,474	48,301	5,106	363,067	363,067	0	0
Hocking	106,678	39,000	67,677	21,626	228	21,366	32	17,375	1,471	15,150	754	754	0	0
Holmes	14,748	9,155	5,593	8,160	267	569	7,324	996	860	1	135	135	0	0
Jackson	102,093	76,443	25,650	25,610	394	5,861	19,355	50,833	25,200	1,911	23,722	23,722	0	0
Jefferson	258,095	257,766	330	1,075	6	554	515	256,691	92,794	1,803	162,094	162,094	0	0
Lawrence	182,593	166,429	16,163	33,441	373	26,095	6,974	132,988	62,633	31,130	39,225	39,225	0	0
Mahoning	21,008	20,338	670	7,774	1	1,081	6,692	12,564	10,380	18	2,165	2,165	0	0
Meigs	37,839	37,839	0	0	0	0	0	37,839	35,523	8	2,308	1,541	767	0
Monroe	350,266	350,266	0	0	0	0	0	350,266	96,321	5,827	248,118	140,247	105,152	2,719
Morgan	383,327	368,247	15,080	596	0	41	555	367,650	35,107	13,735	318,809	318,809	0	0
Muskingum	388,517	312,556	75,962	63,265	728	9,543	52,994	249,291	3,151	7,308	238,832	238,832	0	0
Noble	277,520	276,768	752	0	0	0	0	276,768	66,402	3,923	206,443	206,401	42	0
Perry	443,358	182,930	260,427	73,479	355	49,694	23,430	109,451	5,334	58,472	45,645	45,645	0	0
Scioto	231	129	102	125	6	119	4	4	4	0	0	0	0	0
Stark	60,742	42,812	17,930	25,448	96	6,473	18,879	17,364	4,795	347	12,221	12,221	0	0
Tuscarawas	387,000	244,163	142,837	69,154	358	8,535	60,261	175,010	32,594	3,150	139,266	139,266	0	0
Vinton	104,810	96,414	8,396	23,201	249	13,549	9,403	73,213	46,119	15,441	11,652	11,652	0	0
Washington	258,667	258,667	0	0	0	0	0	258,667	218,033	1,623	39,010	23,880	15,120	0
Wayne	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ohio Total²	5,739,865	4,792,385	947,480	491,406	3,905	192,220	295,281	4,300,979	1,079,391	221,794	2,999,791	2,847,172	149,900	2,719

¹Thousands of short tons.

²Any tally inconsistencies are due to rounding of tonnages to the nearest ton.

TABLE A3. Total estimation of inferred coal tonnages¹ for the Middle Kittanning (No. 6) coal bed in Ohio, by county and type of availability

County	Original Resources	Remaining Resources	Mined Resources	Surface-Minable				Deep-Minable				Depth of Overburden			
				Remaining Surface-Minable	Technologically Restricted Surface-Minable	Land-Use Restricted Surface-Minable	Available Surface-Minable	Remaining Deep-Minable	Technologically Restricted Deep-Minable	Land-Use Restricted Deep-Minable	Available Deep-Minable	Available Deep-Minable Coal 0-1,000 ft of Overburden	Available Deep-Minable Coal 1,000-1,500 ft of Overburden	Available Deep-Minable Coal >1,500 ft of Overburden	
Athens	583,286	529,801	53,485	7,165	0	5,070	2,096	522,635	237,199	19,174	266,262	258,650	7,612	0	
Belmont	1,183,280	1,183,280	0	0	0	0	0	1,183,280	263,953	2,322	917,003	719,731	197,272	0	
Carroll	588,360	585,969	2,391	27,233	4	8,644	18,584	558,736	172,951	11,256	374,529	374,529	0	0	
Columbiana	431,975	430,150	1,824	39,128	53	9,015	30,060	391,022	376,300	233	14,490	14,490	0	0	
Costaon	78,260	45,139	33,121	27,911	845	3,890	23,177	17,228	3,174	191	13,862	13,862	0	0	
Gallia	447,287	445,032	2,255	4,234	0	1,210	3,024	440,799	353,426	3,957	83,415	83,415	0	0	
Guernsey	1,272,876	1,270,384	2,492	31,412	15	13,622	17,775	1,238,973	42,236	58,101	1,138,636	1,138,636	0	0	
Harrison	825,028	824,979	49	8,907	0	4,285	4,622	816,072	61,235	13,732	741,106	741,106	0	0	
Hocking	35,701	23,596	12,104	14,333	291	13,903	139	9,264	78	9,186	0	64	0	0	
Holmes	5,446	4,546	901	4,172	207	177	3,788	373	310	0	64	64	0	0	
Jackson	40,571	38,567	2,004	6,096	247	1,232	4,618	32,471	16,395	524	15,551	15,551	0	0	
Jefferson	726,402	726,387	15	1,386	0	925	462	725,001	232,842	4,587	487,572	487,547	25	0	
Lawrence	455,940	446,767	9,173	18,760	245	15,742	2,773	428,007	225,063	48,991	153,953	153,953	0	0	
Mahoning	58,942	55,023	3,919	29,726	30	4,025	25,671	25,296	23,477	38	1,781	1,781	0	0	
Meigs	33,293	33,293	0	0	0	0	0	33,293	32,786	14	493	314	179	0	
Monroe	890,473	890,473	0	0	0	0	0	890,473	297,542	11,030	581,899	203,398	368,751	9,751	
Morgan	824,775	817,488	7,287	303	0	36	286	817,185	188,381	17,505	611,298	611,298	0	0	
Muskingum	892,933	875,215	17,718	49,761	354	8,697	40,709	825,454	264	26,407	798,782	798,782	0	0	
Noble	1,010,530	1,010,417	112	0	0	0	0	1,010,417	105,283	12,451	892,683	892,677	5	0	
Perry	118,913	43,528	75,385	12,028	133	6,513	5,381	31,501	680	13,885	16,936	16,936	0	0	
Scioto	591	380	211	375	94	184	97	5	5	0	0	0	0	0	
Stark	96,026	91,673	4,354	38,910	86	4,210	34,615	52,762	30,756	643	21,363	21,363	0	0	
Tuscarawas	397,314	324,501	72,813	46,246	277	6,051	39,917	278,256	27,497	6,817	243,941	243,941	0	0	
Vinton	87,002	86,376	626	18,161	202	11,213	6,746	68,215	58,963	8,015	1,237	1,237	0	0	
Washington	446,924	446,924	0	0	0	0	0	446,924	406,673	1,683	38,567	24,096	14,471	0	
Wayne	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Ohio Total²	11,532,128	11,229,888	302,239	386,247	3,084	118,644	264,519	10,843,641	3,157,466	270,743	7,415,423	6,817,357	588,315	9,751	

¹Thousands of short tons.

²Any tally inconsistencies are due to rounding of tonnages to the nearest ton.

TABLE A4. Total estimation of Measured coal tonnages¹ for the Lower Kittanning (No. 5) coal bed in Ohio, by county and type of availability

County	Original Resources	Remaining Resources	Mined Resources	Surface-Minable				Deep-Minable				Depth of Overburden		
				Remaining Surface-Minable	Technologically Restricted Surface-Minable	Land-Use Restricted Surface-Minable	Available Surface-Minable	Remaining Deep-Minable	Technologically Restricted Deep-Minable	Land-Use Restricted Deep-Minable	Available Deep-Minable	Available Deep-Minable Coal 0-1,000 ft of Overburden	Available Deep-Minable Coal 1,000-1,500 ft of Overburden	Available Deep-Minable Coal >1,500 ft of Overburden
Athens	30,430	30,000	430	324	2	322	0	29,676	21,423	320	7,933	7,761	172	0
Belmont	30,292	30,292	0	0	0	0	0	30,292	11,129	168	18,996	14,947	4,048	0
Carrill	50,672	49,671	7,001	2,782	3	658	2,121	40,889	15,989	437	24,463	24,463	0	0
Columbiana	50,984	45,100	5,884	10,253	3	3,650	6,601	34,847	18,489	295	16,063	16,063	0	0
Coshocton	33,915	9,288	24,627	5,475	61	359	5,055	3,813	2,937	20	856	856	0	0
Gallia	18,450	17,475	975	669	0	596	73	16,806	7,225	1,212	8,368	8,368	0	0
Guernsey	13,281	11,966	1,315	909	0	362	547	11,057	3,007	820	7,230	7,230	0	0
Harrison	67,414	67,414	0	70	0	31	39	67,344	17,990	509	48,845	48,845	0	0
Hocking	4,720	3,330	1,390	1,432	35	1,259	139	1,898	1,857	41	0	0	0	0
Holmes	17,659	11,261	6,397	9,028	38	631	8,359	2,233	1,607	10	616	616	0	0
Jackson	44,550	22,359	22,191	14,294	99	3,902	10,293	8,065	2,156	663	5,246	5,246	0	0
Jefferson	37,254	36,732	522	2,681	2	1,866	813	34,051	8,564	310	25,177	25,177	0	0
Lawrence	18,287	14,216	4,070	5,536	41	4,764	731	8,680	2,919	4,460	1,301	1,301	0	0
Mahoning	21,390	15,773	5,617	8,943	9	1,268	7,667	6,829	2,003	2	4,825	4,825	0	0
Meigs	76,734	47,271	29,464	0	0	0	0	47,271	7,833	906	38,532	35,372	3,160	0
Monroe	49,796	49,796	0	0	0	0	0	49,796	20,448	1,117	28,230	14,701	13,529	0
Morgan	29,176	29,176	0	0	0	0	0	29,176	11,089	429	17,658	17,658	0	0
Muskingum	24,670	21,607	3,063	4,380	21	412	3,947	17,227	2,198	233	14,796	14,796	0	0
Noble	39,359	39,359	0	0	0	0	0	39,359	12,196	920	26,242	26,170	72	0
Perry	19,847	8,576	11,271	6,329	79	2,141	4,110	2,247	1,148	311	787	787	0	0
Scioto	1,027	817	210	815	4	666	145	2	2	0	0	0	0	0
Stark	25,612	11,331	14,282	6,349	32	2,788	3,529	4,981	2,490	42	2,449	2,449	0	0
Tuscarawas	95,400	49,639	45,761	17,418	124	2,649	14,645	32,221	18,850	190	13,181	13,181	0	0
Vinton	76,394	41,644	34,749	16,577	24	6,532	10,021	25,068	3,040	2,623	19,405	19,405	0	0
Washington	107,697	107,697	0	0	0	0	0	107,697	49,906	3,010	54,781	26,594	28,187	0
Wayne	1,126	699	427	502	2	72	428	197	84	3	110	110	0	0
Ohio Total²	986,133	766,487	219,646	114,768	580	34,928	79,261	651,719	246,579	19,050	386,090	336,921	49,169	0

¹Thousands of short tons.

²Any tally inconsistencies are due to rounding of tonnages to the nearest ton.

TABLE A5. Total estimation of indicated coal tonnages¹ for the Lower Kittanning (No. 5) coal bed in Ohio, by county and type of availability

County	Original Resources	Remaining Resources	Mined Resources	Surface-Minable				Deep-Minable				Depth of Overburden			
				Remaining Surface-Minable	Technologically Restricted Surface-Minable	Land-Use Restricted Surface-Minable	Available Surface-Minable	Remaining Deep-Minable	Technologically Restricted Deep-Minable	Land-Use Restricted Deep-Minable	Available Deep-Minable	Available Deep-Minable Coal 0-1,000 ft of Overburden	Available Deep-Minable Coal 1,000-1,500 ft of Overburden	Available Deep-Minable Coal >1,500 ft of Overburden	
Athens	155,201	154,709	492	771	1	770	0	153,938	123,109	571	30,258	27,590	2,668	0	
Belmont	185,320	185,320	0	0	0	0	0	185,320	72,532	553	112,234	88,730	23,504	0	
Carroll	269,476	256,116	13,360	8,847	14	1,788	7,045	247,269	93,108	2,311	151,850	151,850	0	0	
Columbiana	204,703	193,147	11,556	21,802	21	9,526	12,254	171,345	88,798	793	81,754	81,754	0	0	
Coshocton	54,952	31,009	23,943	15,904	431	868	14,605	15,105	13,408	30	1,668	1,668	0	0	
Gallia	101,565	97,346	4,220	3,702	0	2,871	831	95,644	45,883	5,620	42,140	42,140	0	0	
Guernsey	98,026	93,904	4,121	3,677	34	1,540	2,103	90,228	29,739	3,878	56,610	56,610	0	0	
Harrison	231,052	231,046	7	351	0	124	226	230,695	87,170	1,447	142,079	142,079	0	0	
Hocking	25,362	18,598	6,764	6,196	169	5,712	314	12,402	12,119	283	0	0	0	0	
Holmes	37,615	28,838	8,777	21,144	245	1,568	19,330	7,694	4,633	59	3,002	3,002	0	0	
Jackson	129,497	85,891	43,606	46,229	438	7,046	38,744	39,662	7,710	1,948	30,005	30,005	0	0	
Jefferson	203,435	202,601	834	1,886	24	1,114	748	200,715	63,697	1,713	135,306	135,306	0	0	
Lawrence	73,786	64,577	9,208	13,578	130	10,013	3,435	50,999	22,890	17,196	10,913	10,913	0	0	
Mahoning	77,642	68,219	9,423	28,856	10	4,438	24,408	39,363	15,307	276	23,781	23,781	0	0	
Meigs	284,914	190,615	94,299	0	0	0	0	190,615	43,282	2,207	145,126	147,502	17,624	0	
Monroe	231,225	231,225	0	0	0	0	0	231,225	122,479	3,227	105,519	53,312	52,207	0	
Morgan	127,594	127,594	0	0	0	0	0	127,594	65,303	858	61,433	61,433	0	0	
Muskingum	123,159	115,488	7,691	12,411	128	2,020	10,263	103,057	20,500	1,773	80,784	80,784	0	0	
Noble	246,725	246,725	0	0	0	0	0	246,725	72,622	3,891	170,212	167,699	2,513	0	
Perry	76,187	44,405	31,782	21,265	296	8,960	12,009	23,140	17,424	1,503	4,214	4,214	0	0	
Scioto	2,993	2,783	211	2,765	182	2,201	382	18	0	18	0	0	0	0	
Stark	68,927	42,393	26,534	22,293	166	6,363	15,764	20,100	11,169	288	8,643	8,643	0	0	
Tuscarawas	220,460	163,632	56,828	45,516	368	5,829	39,319	118,116	79,814	654	37,648	37,648	0	0	
Vinton	227,210	172,155	55,056	44,532	114	21,502	22,916	127,622	19,794	19,054	88,774	88,774	0	0	
Washington	433,589	433,589	0	0	0	0	0	433,589	215,603	7,144	210,841	101,171	109,670	0	
Wayne	386	201	185	198	3	36	159	3	3	0	0	0	0	0	
Ohio Total²	3,891,003	3,482,105	408,897	321,921	2,774	94,293	224,855	3,160,184	1,348,095	77,294	1,734,792	1,526,606	208,187	0	

¹Thousands of short tons.

²Any tally inconsistencies are due to rounding of tonnages to the nearest ton.

TABLE A6. Total estimation of Inferred coal tonnages¹ for the Lower Kittanning (No. 5) coal bed in Ohio, by county and type of availability

County	Original Resources	Remaining Resources	Mined Resources	Surface-Minable				Deep-Minable				Depth of Overburden		
				Remaining Surface-Minable	Technologically Restricted Surface-Minable	Land-Use Restricted Surface-Minable	Available Surface-Minable	Remaining Deep-Minable	Technologically Restricted Deep-Minable	Land-Use Restricted Deep-Minable	Available Deep-Minable	Available Deep-Minable Coal 0-1,000 ft of Overburden	Available Deep-Minable Coal 1,000-1,500 ft of Overburden	Available Deep-Minable Coal >1,500 ft of Overburden
Athens	398,615	396,375	2,240	3,175	0	3,052	123	393,200	366,136	328	267,37	20,074	6,663	0
Belmont	1,039,348	1,039,348	0	0	0	0	0	1,039,348	373,849	1,456	664,043	552,916	111,127	0
Carrroll	561,407	555,742	5,665	17,615	0	6,490	11,124	538,128	277,660	7,084	253,382	253,382	0	0
Columbiana	763,559	759,652	3,907	73,356	20	23,316	50,019	686,297	365,448	6,001	314,847	314,847	0	0
Coshocton	94,714	68,656	26,058	29,433	662	2,484	26,287	39,223	38,109	16	1,098	1,098	0	0
Gallia	385,015	383,490	1,525	3,164	0	1,770	1,394	380,326	318,641	5,749	55,936	55,936	0	0
Guernsey	925,899	922,956	2,943	18,970	7	8,209	10,755	903,985	350,114	21,016	532,854	532,854	0	0
Harrison	519,699	519,460	239	2,644	0	763	1,881	516,816	269,750	1,920	245,146	245,146	0	0
Hocking	28,817	22,825	5,992	6,006	284	5,465	257	16,819	16,812	7	0	0	0	0
Holmes	15,816	14,430	1,387	13,405	185	717	12,503	1,024	856	7	161	161	0	0
Jackson	77,910	69,222	8,689	21,202	544	1,658	19,000	48,019	35,945	152	11,922	11,922	0	0
Jefferson	747,954	747,954	0	384	12	344	29	747,569	312,012	4,496	431,060	430,942	117	0
Lawrence	257,532	254,996	2,536	7,211	71	6,011	1,128	247,785	225,383	7,877	14,523	14,523	0	0
Mahoning	159,464	151,532	7,932	78,284	28	14,340	63,916	73,248	14,976	821	57,451	57,451	0	0
Meigs	453,741	450,197	3,544	4	0	1	3	450,193	238,479	2,649	209,064	132,528	76,536	0
Monroe	579,338	579,338	0	0	0	0	0	579,338	411,179	4,092	164,066	62,470	101,596	0
Morgan	521,916	521,916	0	54	0	16	39	521,862	336,648	2,630	182,583	182,583	79	0
Muskingum	581,409	564,301	17,107	28,967	229	4,251	24,487	535,334	261,407	6,899	267,028	267,028	0	0
Noble	841,420	841,420	0	0	0	0	0	841,420	274,722	8,697	558,000	555,463	2,537	0
Perry	123,000	93,551	29,449	24,373	208	6,404	17,760	69,178	59,488	311	9,380	9,380	0	0
Scioto	1,656	1,596	59	1,571	187	1,011	373	25	25	0	0	0	0	0
Stark	113,995	104,409	9,586	27,104	53	5,152	21,899	77,306	37,015	813	39,478	39,478	0	0
Tuscarawas	292,502	257,760	34,742	29,965	222	3,710	26,033	227,795	202,475	508	24,812	24,812	0	0
Vinton	177,947	163,820	14,127	26,319	287	16,519	9,514	137,501	57,957	30,039	49,505	49,505	0	0
Washington	566,358	566,358	0	0	0	0	0	566,358	427,012	4,768	134,578	70,627	63,951	0
Wayne	2,359	2,321	38	2,319	0	86	2,232	2	2	0	0	0	0	0
Ohio Total²	10,231,390	10,053,626	177,764	415,526	2,999	111,770	300,757	9,638,100	5,272,101	118,336	4,247,653	3,885,047	362,607	0

¹Thousands of short tons.

²Any tally inconsistencies are due to rounding of tonnages to the nearest ton.

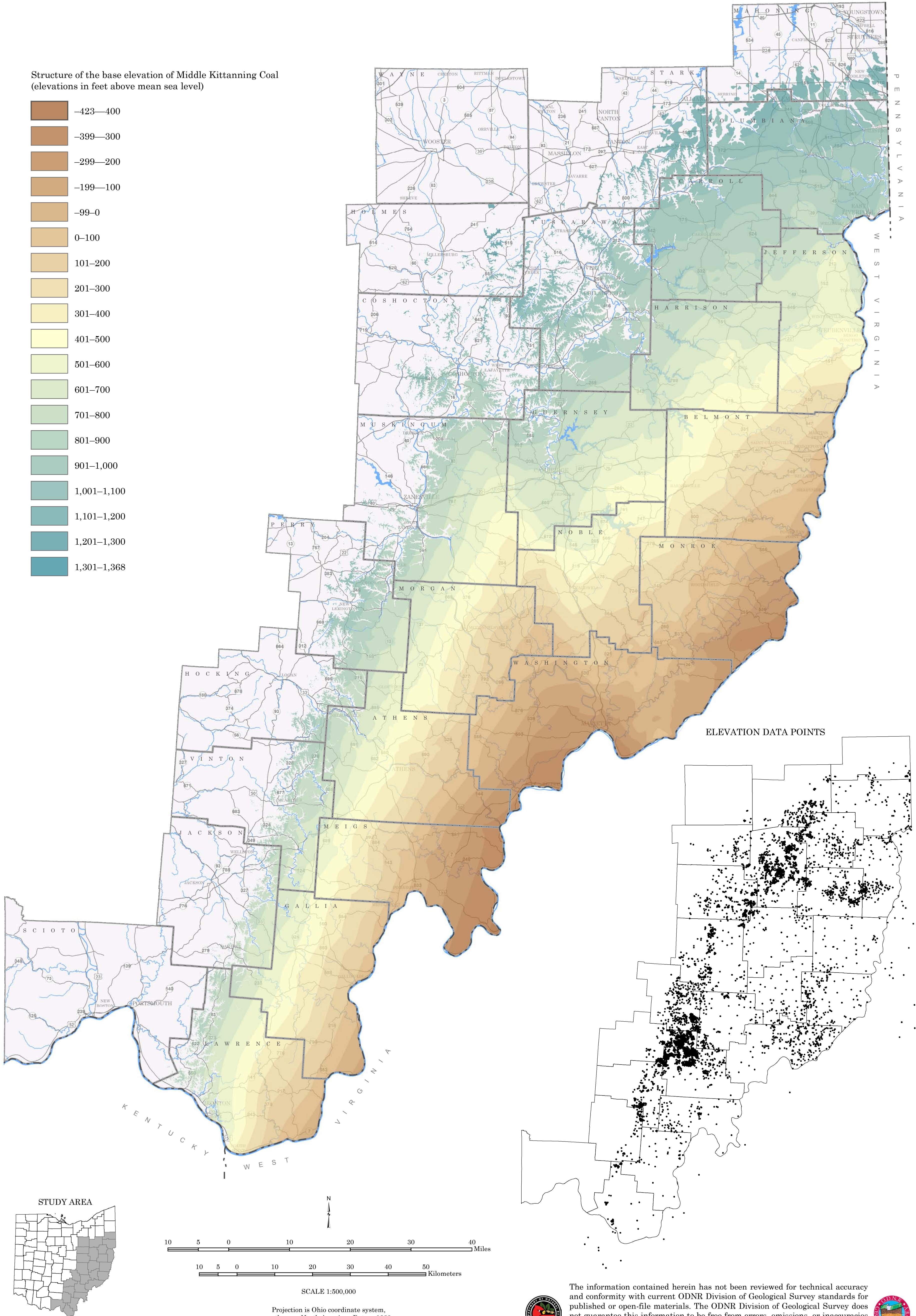
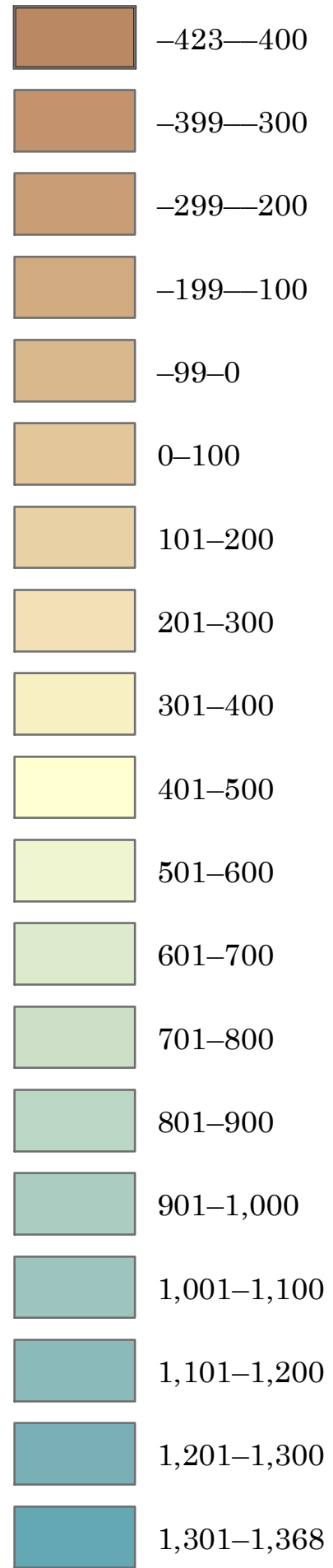


Ohio Department of Natural Resources
Division of Geological Survey
2045 Morse Road, Bldg. C-1
Columbus, OH 43229-6693
Telephone: (614) 265-6576
Fax: (614) 447-1918

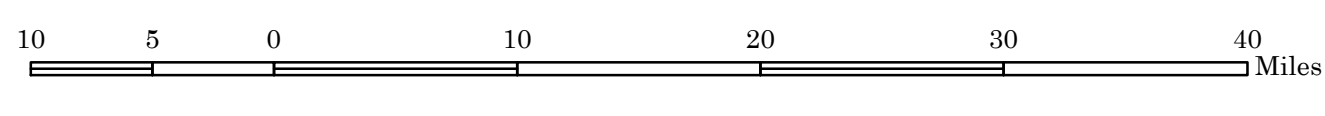
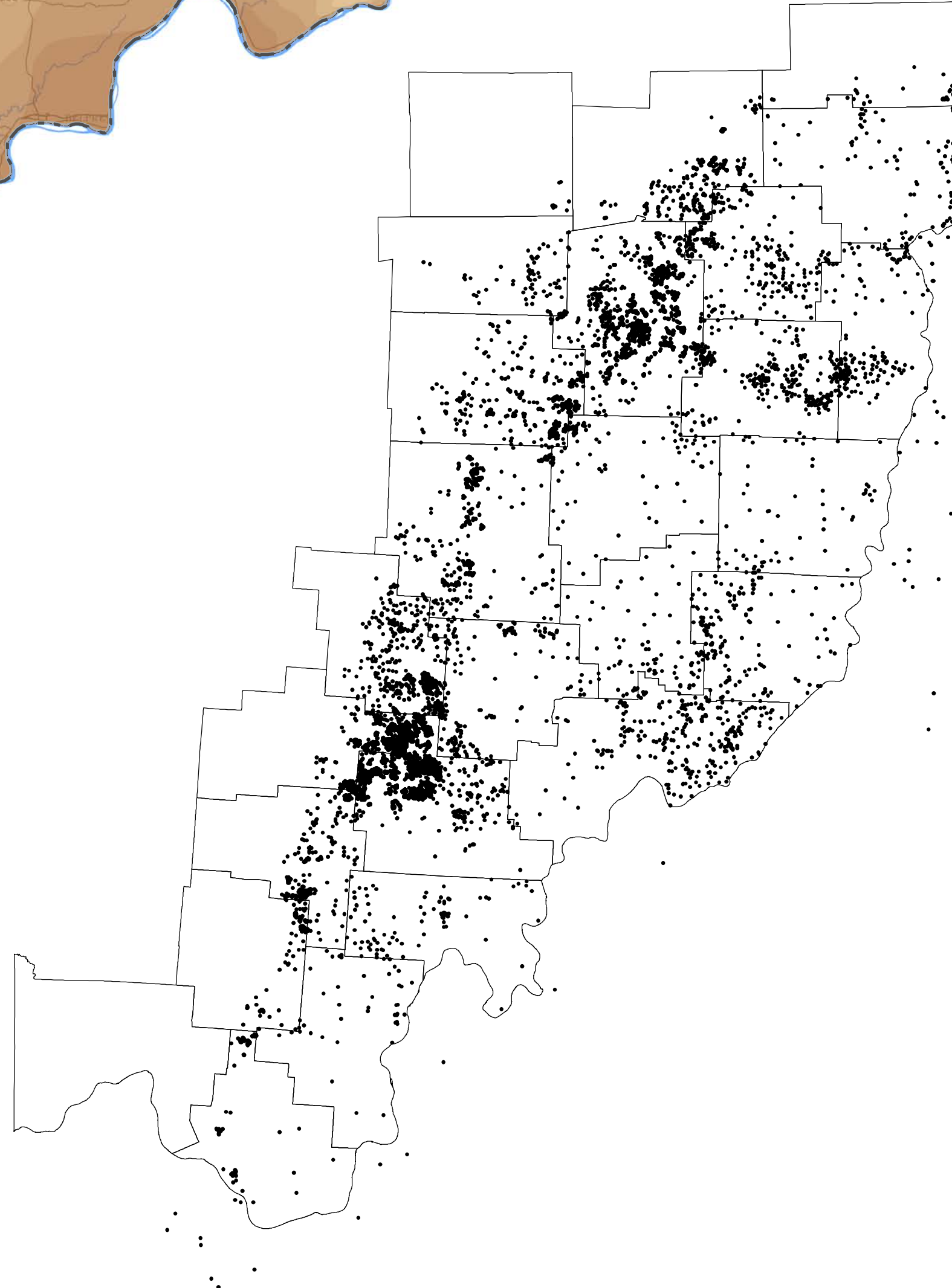
STRUCTURE MAP OF THE MIDDLE KITTANNING (NO. 6) COAL BED IN OHIO

by
Christopher E. Wright and Nathan R. Erber

Structure of the base elevation of Middle Kittanning Coal
(elevations in feet above mean sea level)



ELEVATION DATA POINTS



SCALE 1:500,000

Projection is Ohio coordinate system,
south zone, North American Datum 1983.



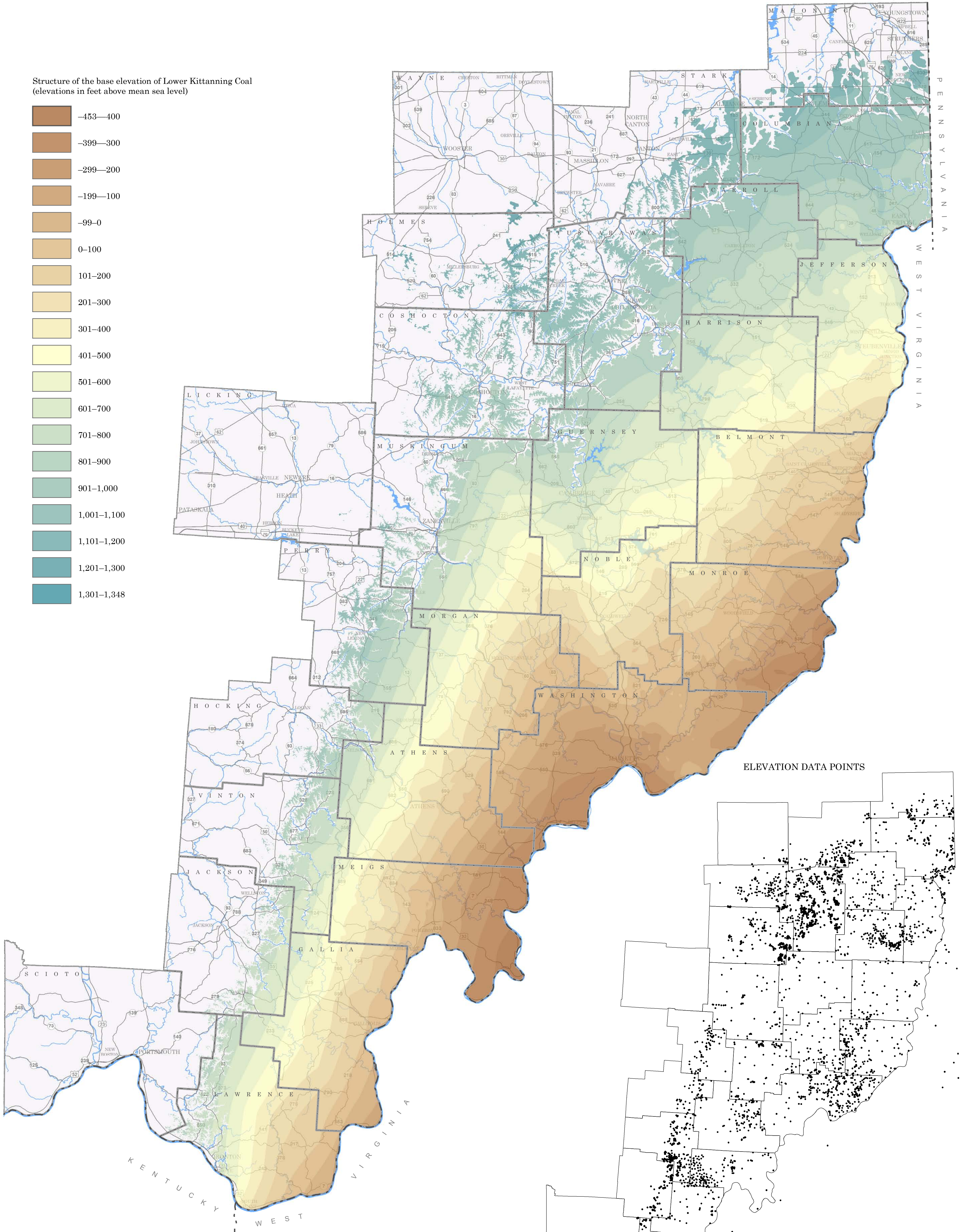
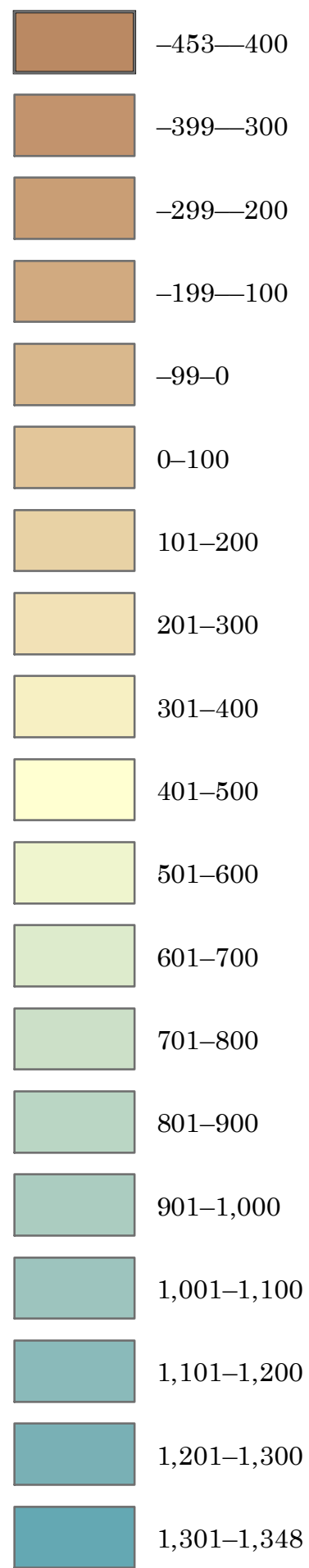
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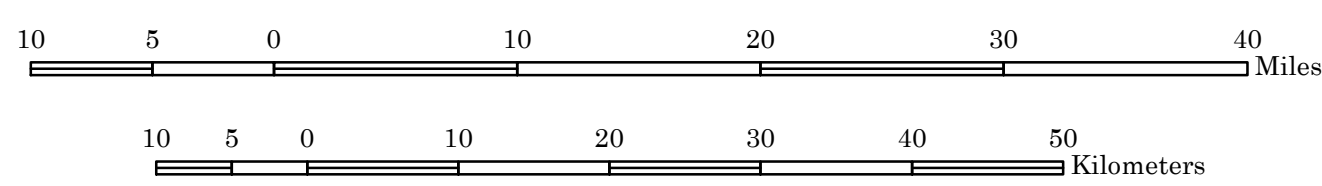
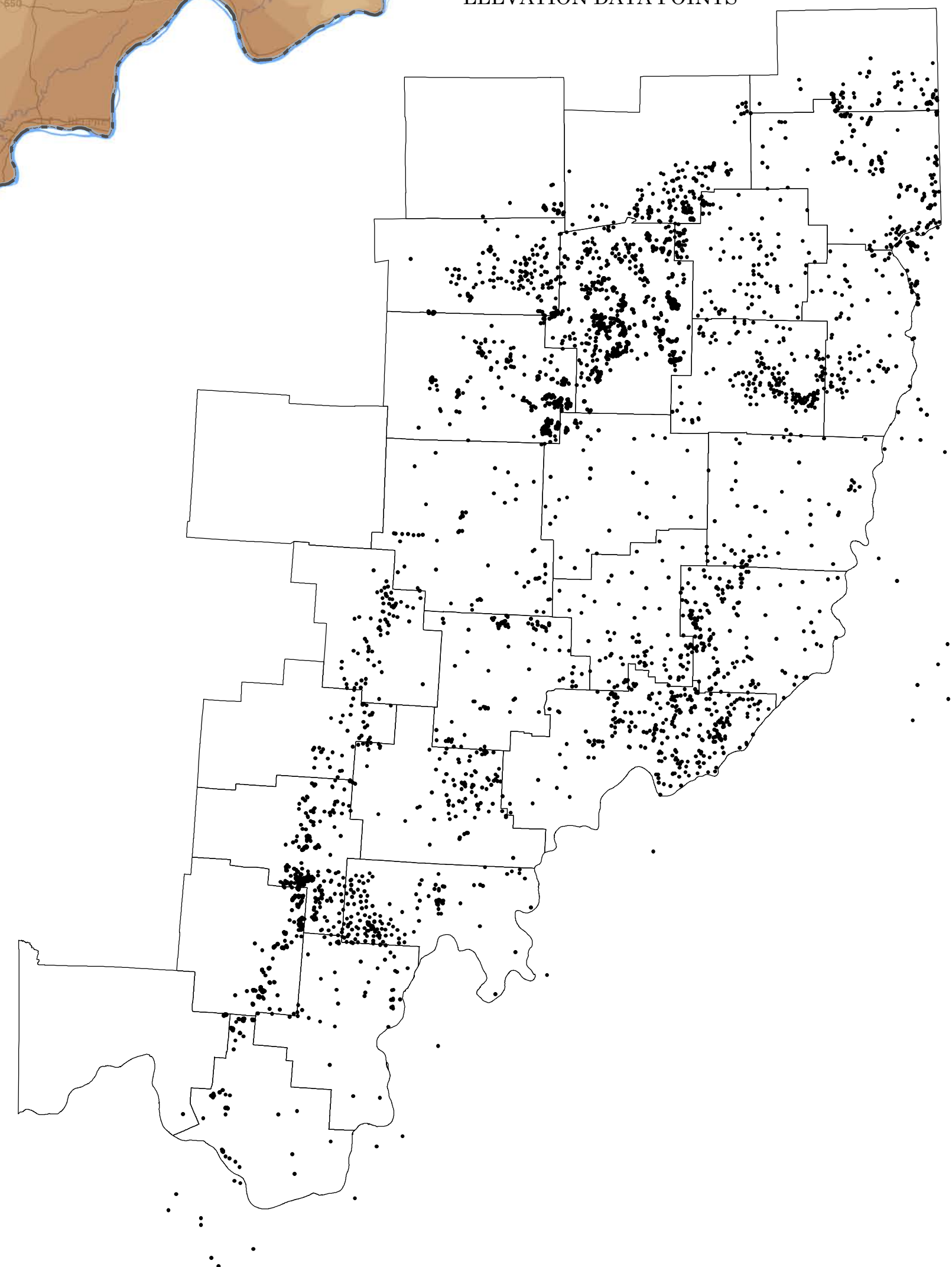
STRUCTURE MAP OF THE LOWER KITTANNING (NO. 5) COAL BED IN OHIO

by
Christopher E. Wright and Nathan R. Erber

Structure of the base elevation of Lower Kittanning Coal
(elevations in feet above mean sea level)



ELEVATION DATA POINTS



SCALE 1:500,000

Projection is Ohio coordinate system,
south zone, North American Datum 1983.



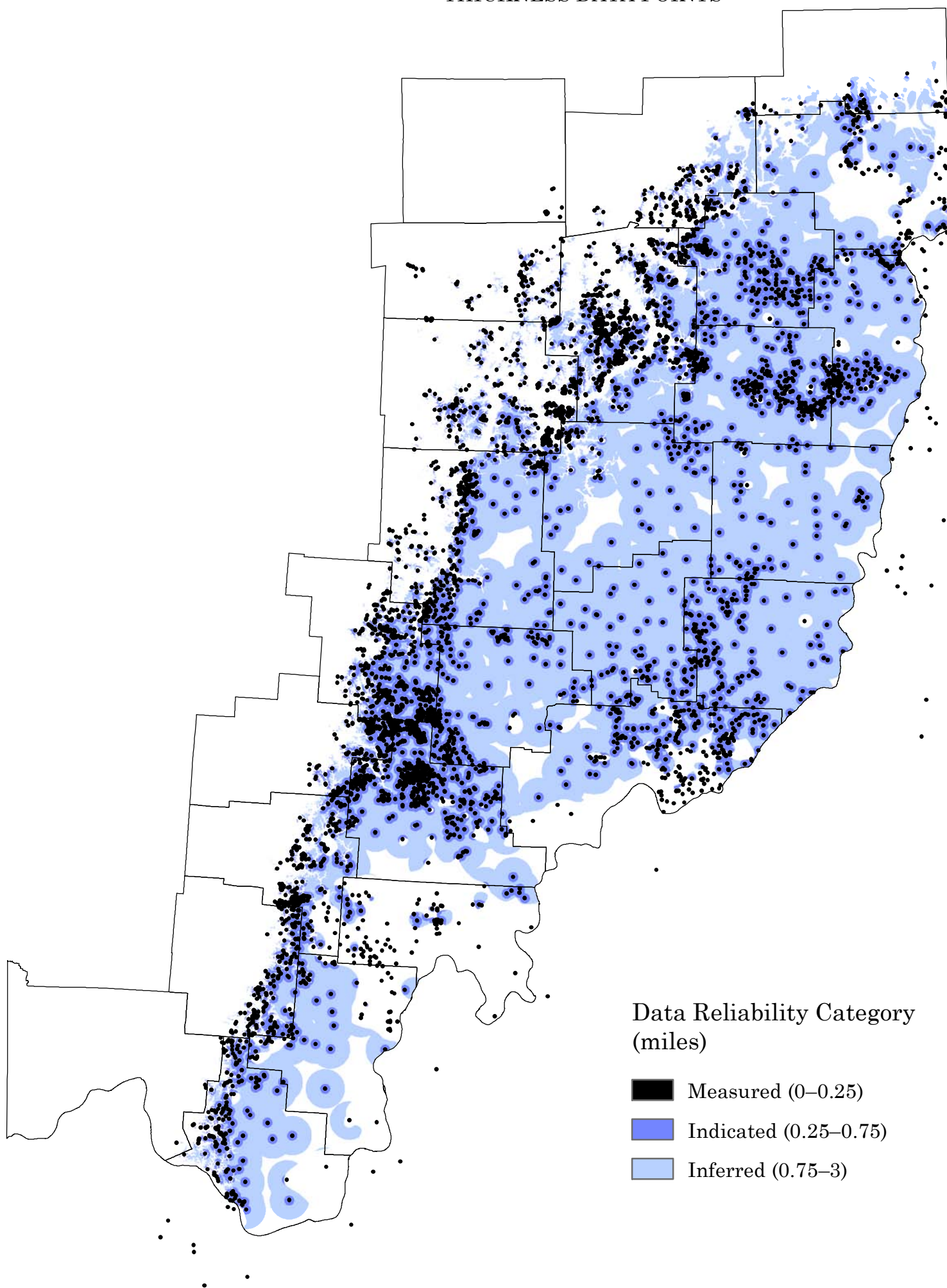
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ORIGINAL RESOURCES ISOPACH OF THE MIDDLE KITTANNING (NO. 6) COAL BED IN OHIO

by
Christopher E. Wright and Nathan R. Erber

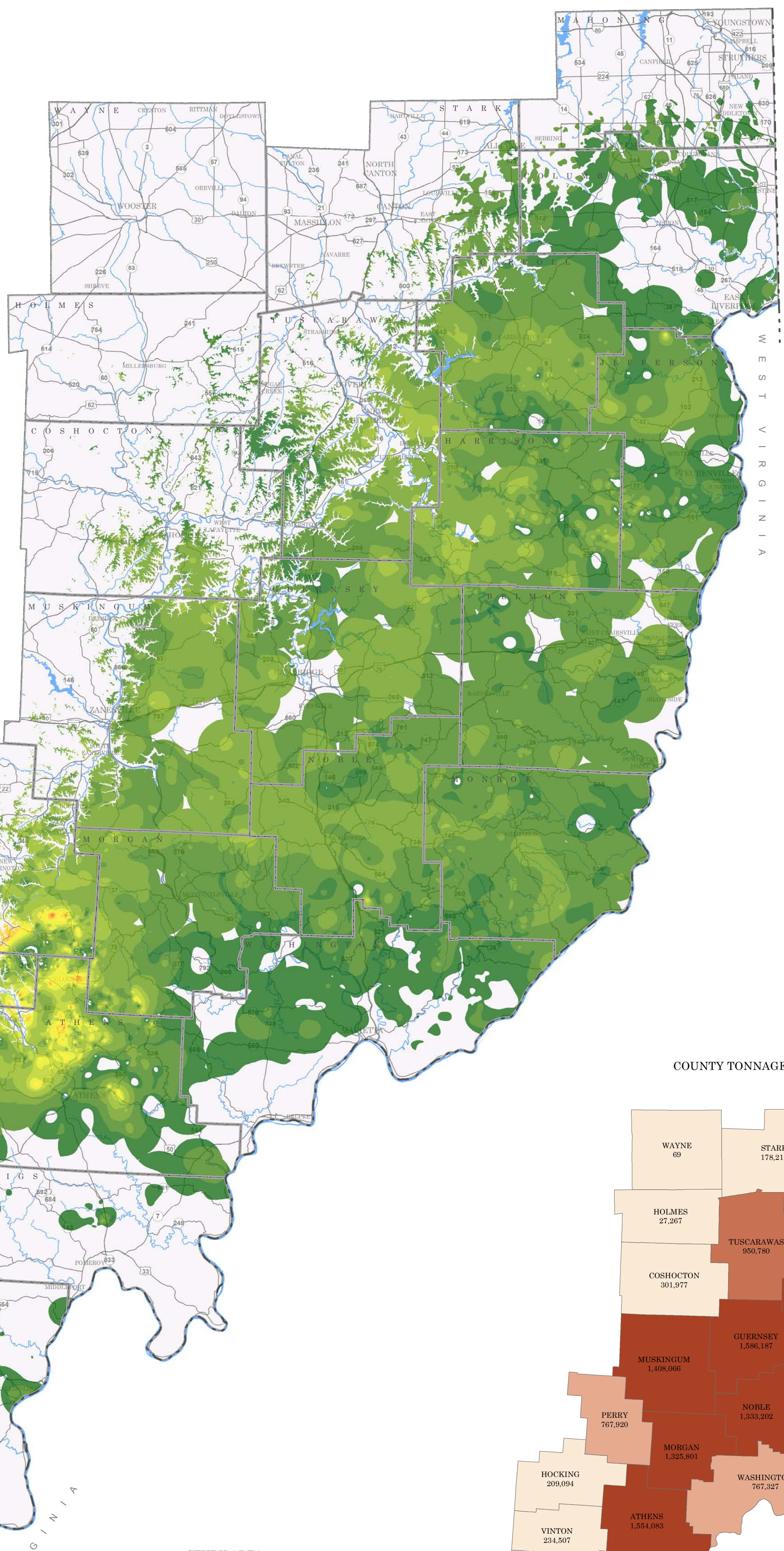
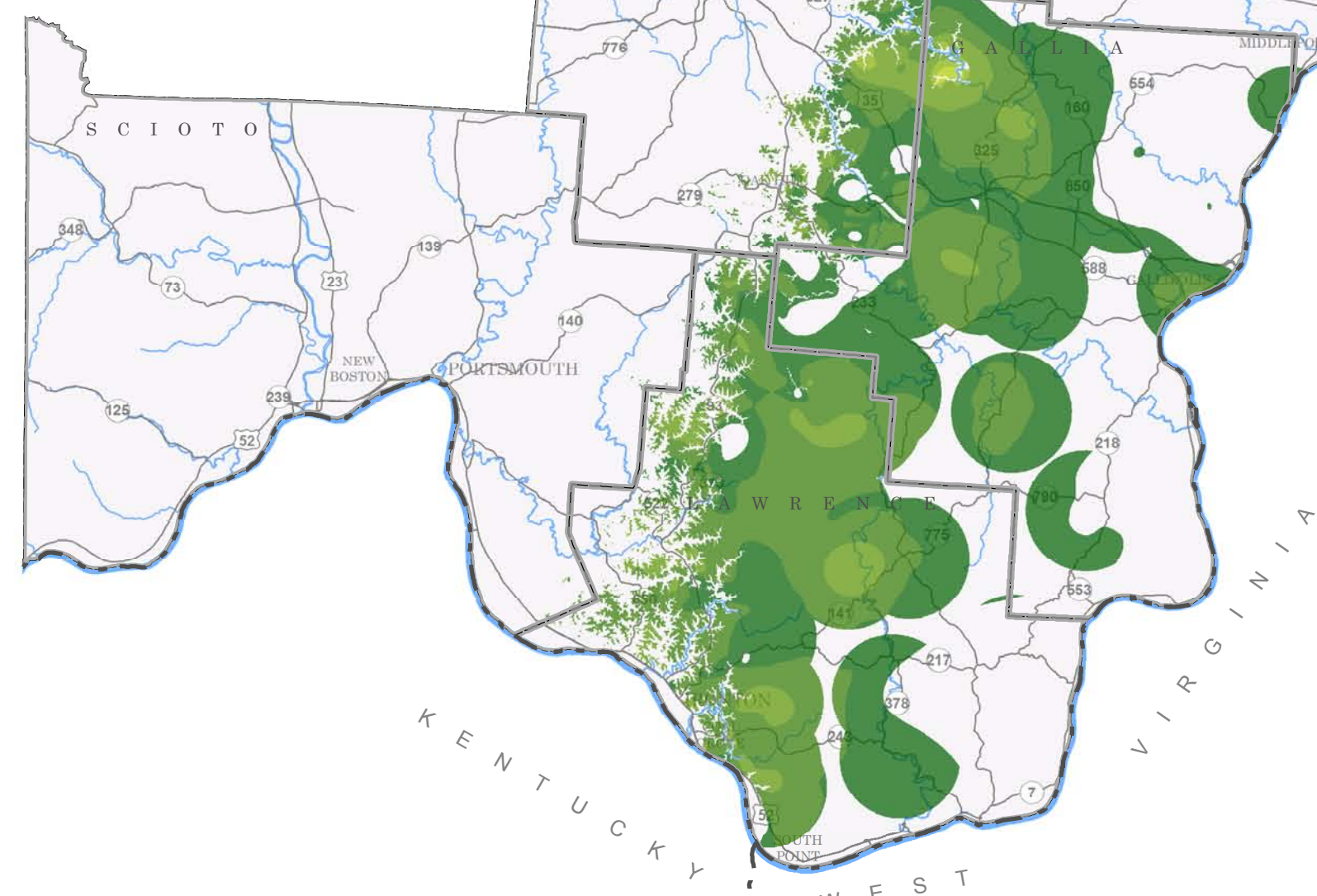
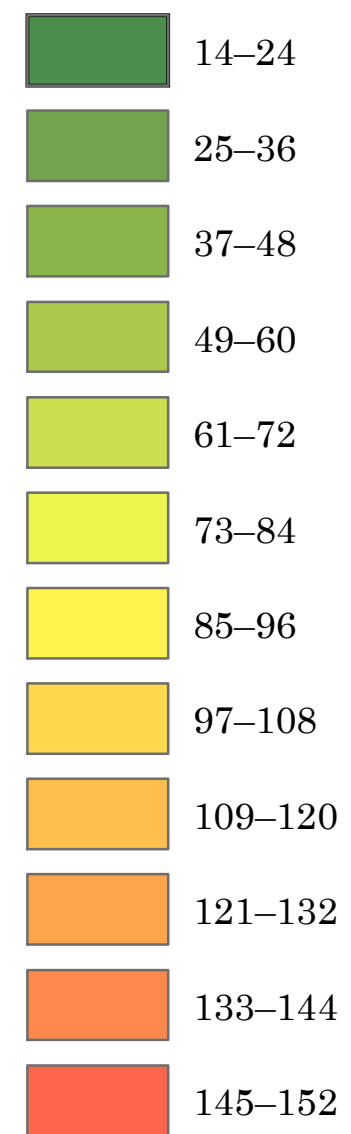
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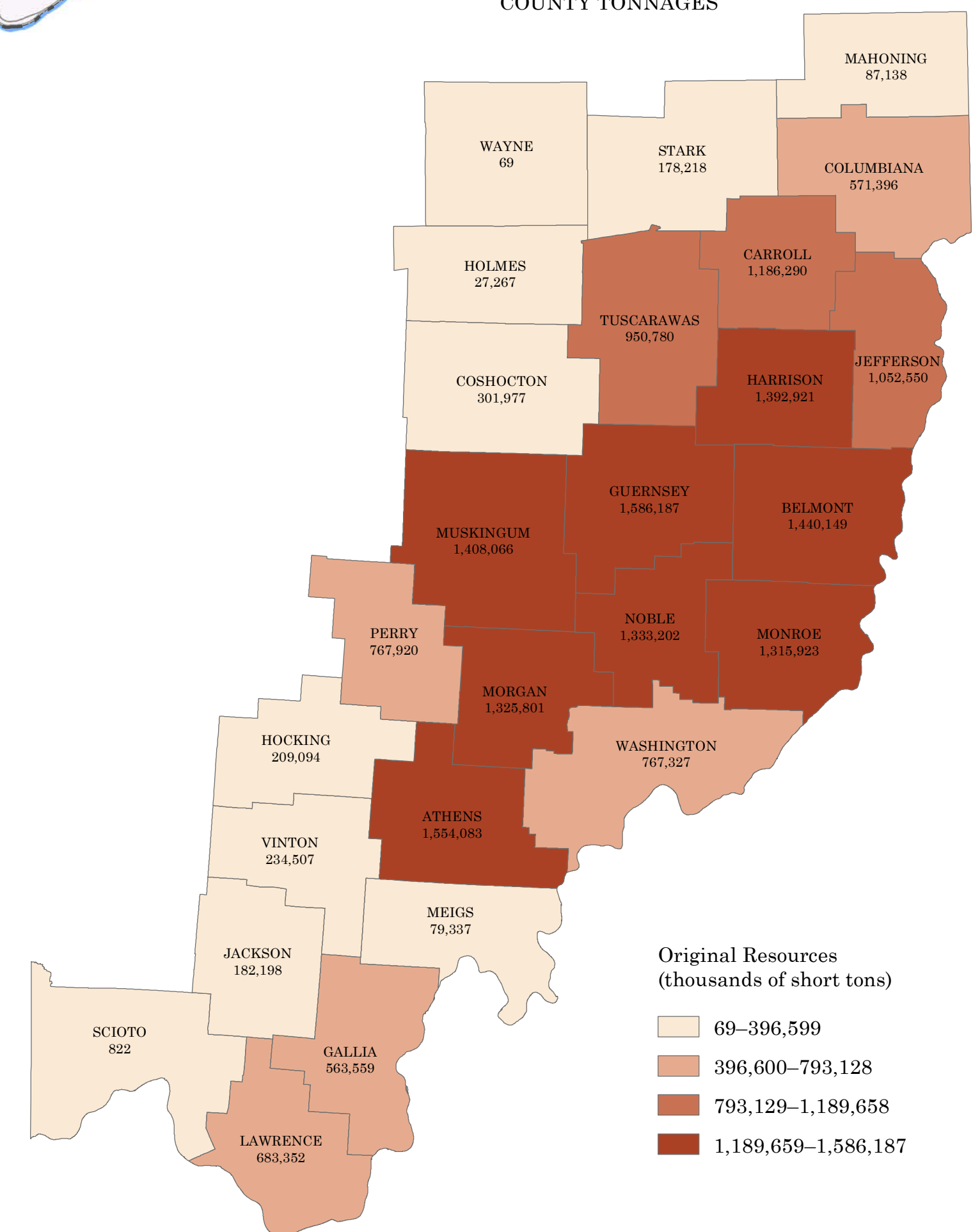
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- Inferred (0.75-3)

Coal Thickness (inches)



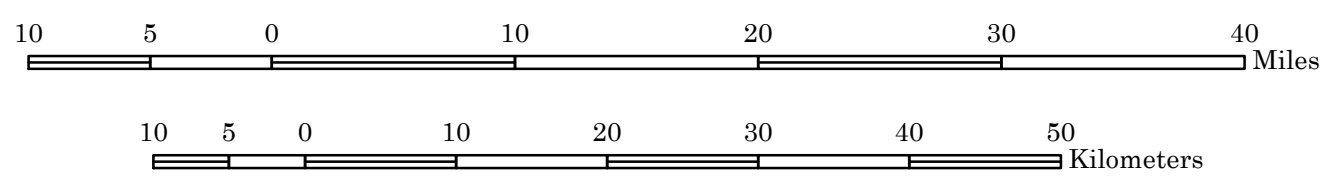
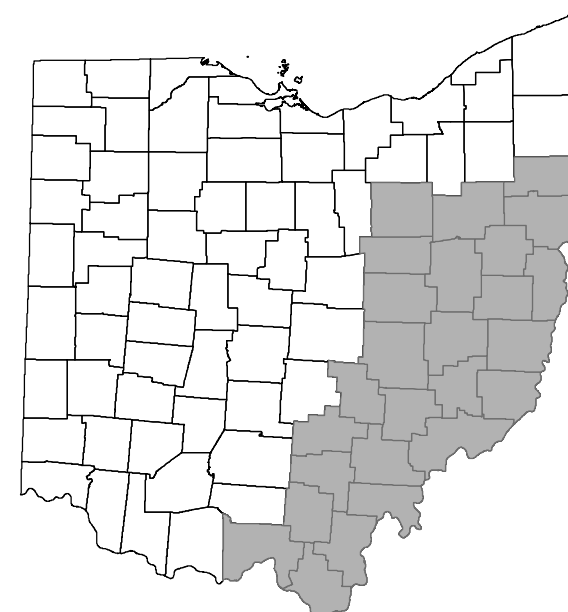
COUNTY TONNAGES



Original Resources (thousands of short tons)

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- 396,600-793,128
- 793,129-1,189,658
- 1,189,659-1,586,187

STUDY AREA



SCALE 1:500,000

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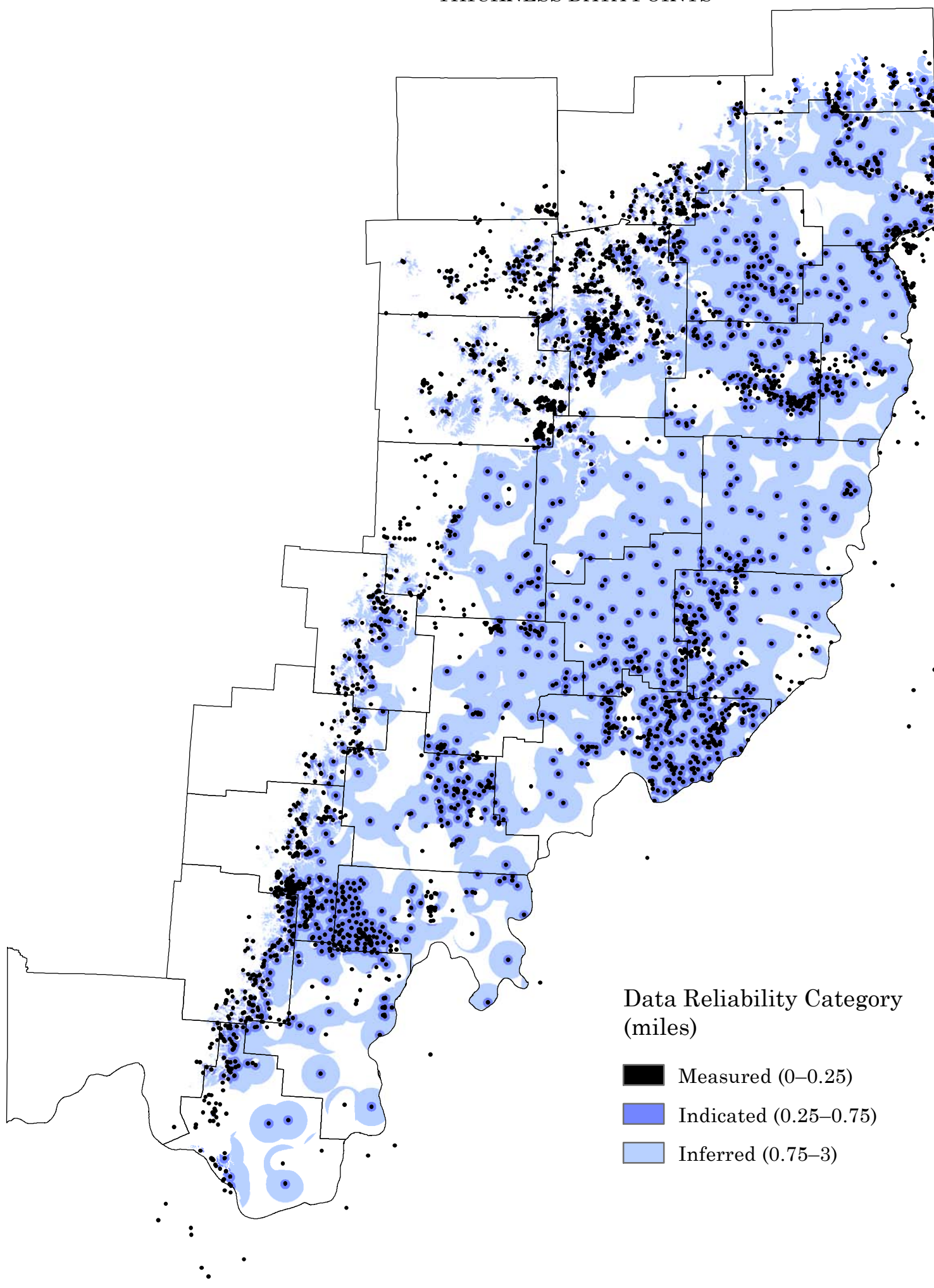


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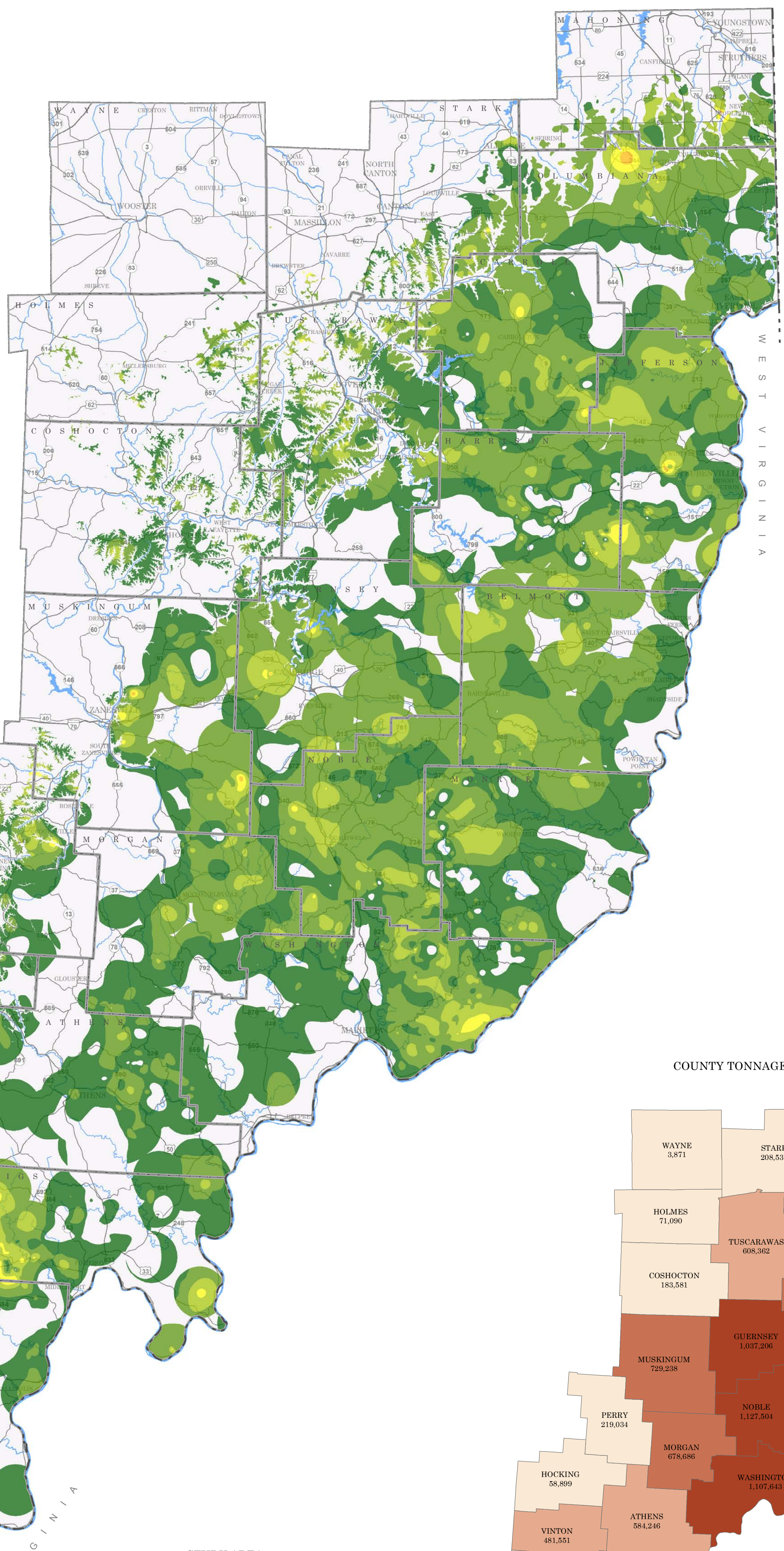
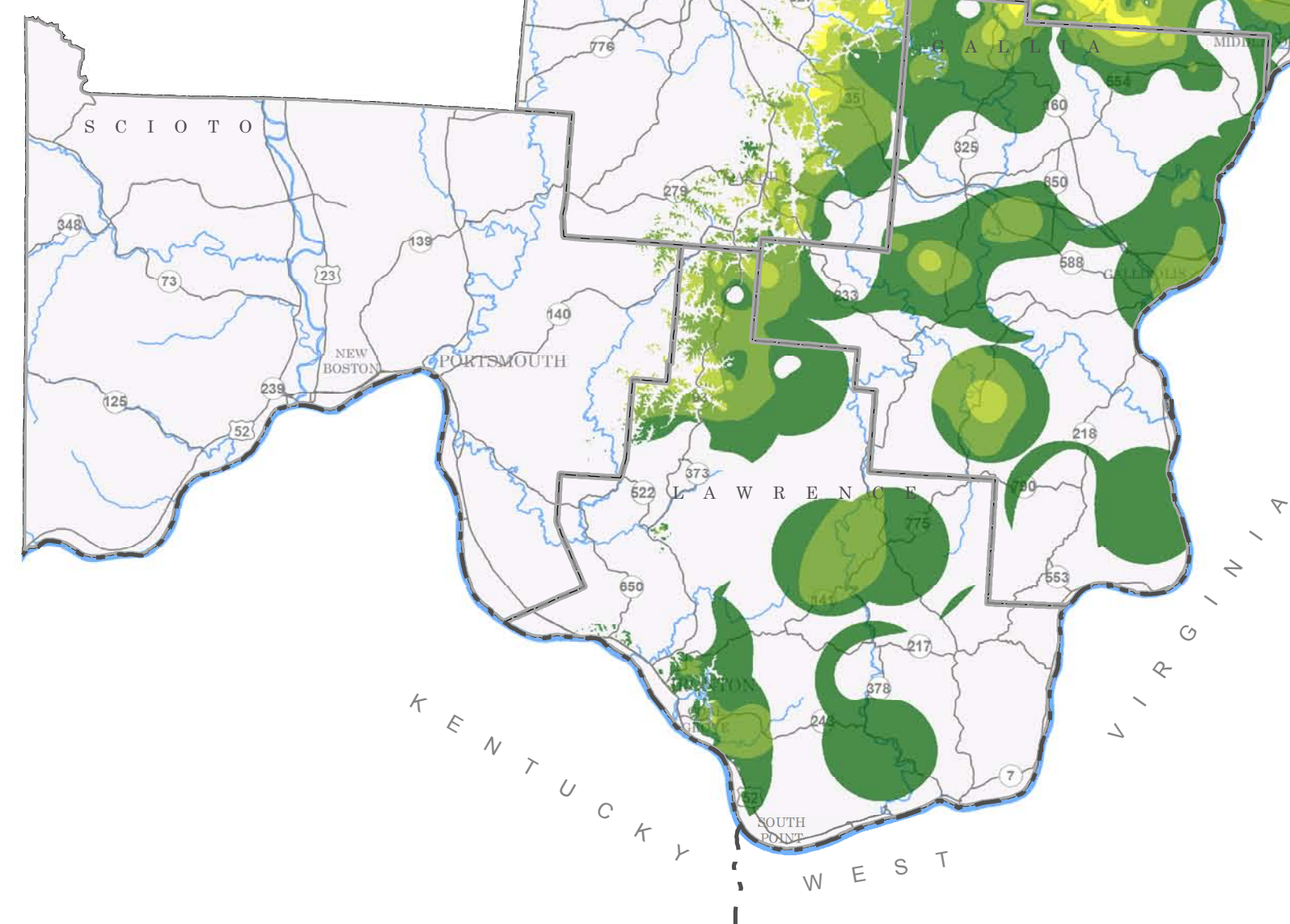
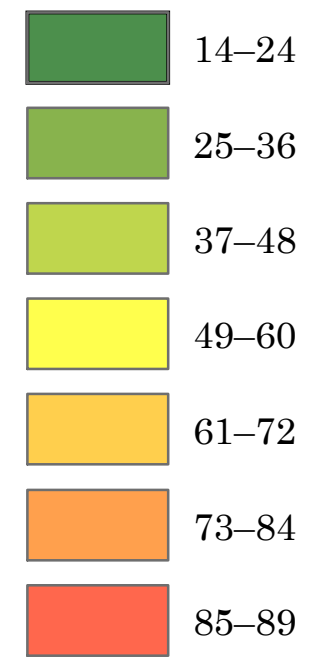
THICKNESS DATA POINTS



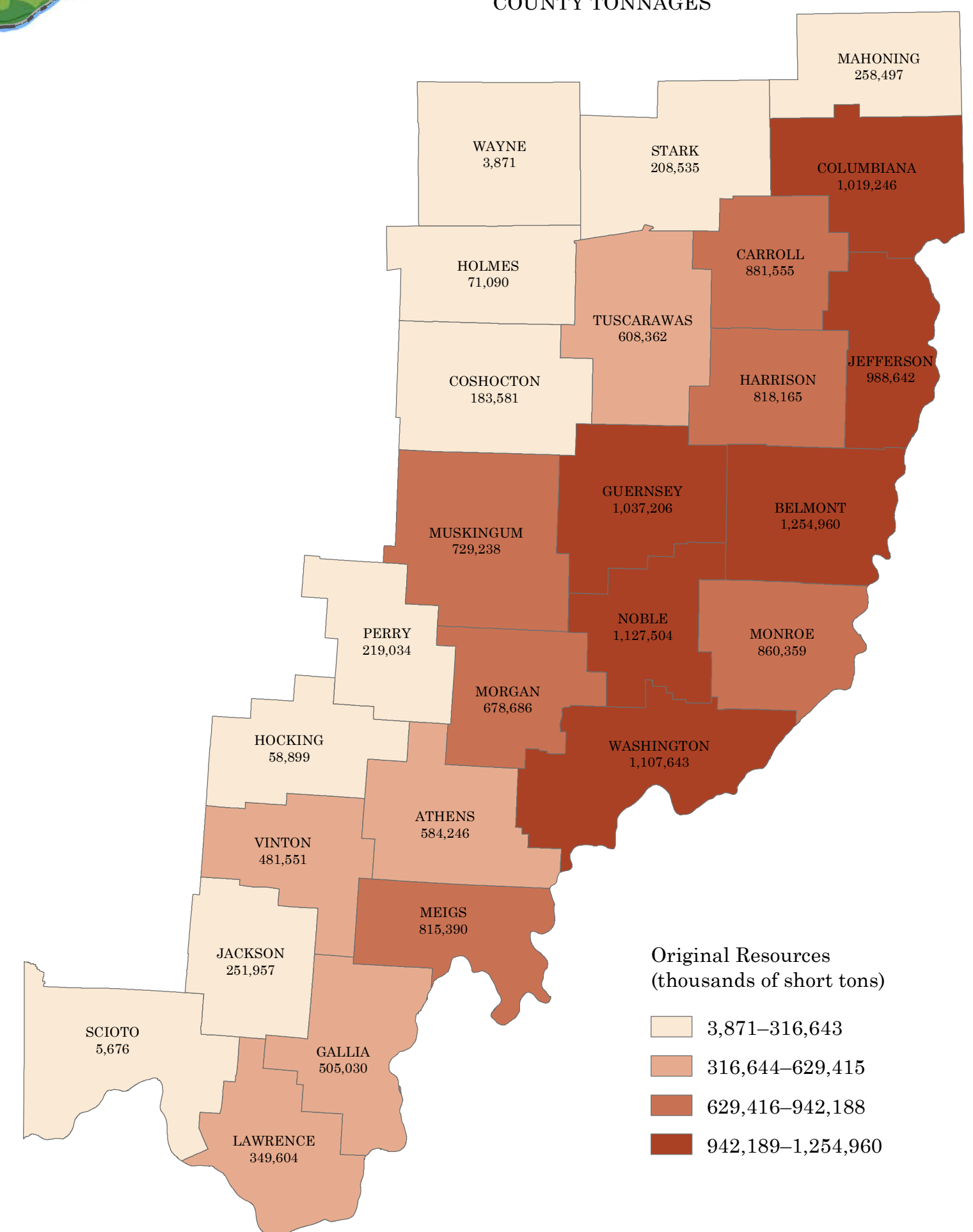
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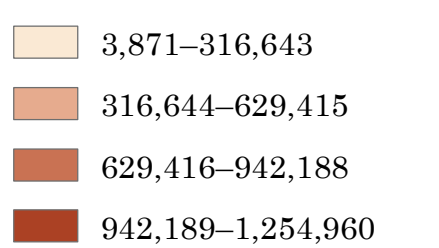
Coal Thickness (inches)



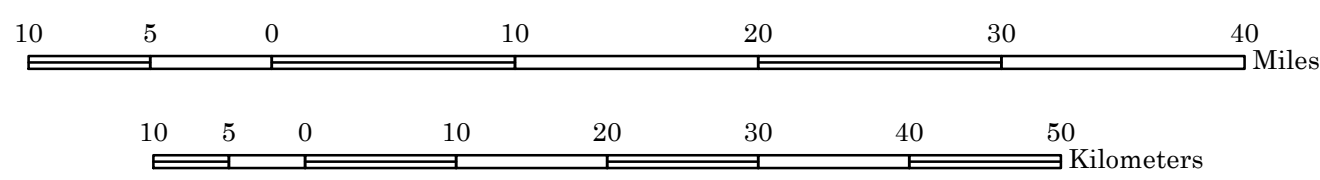
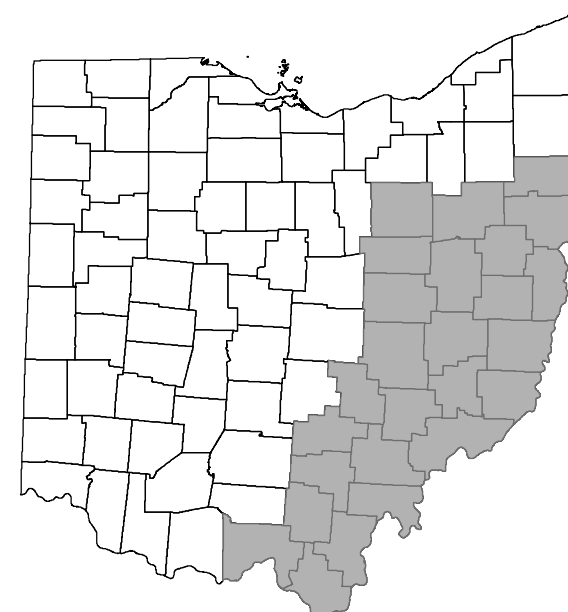
COUNTY TONNAGES



Original Resources (thousands of short tons)



STUDY AREA



SCALE 1:500,000

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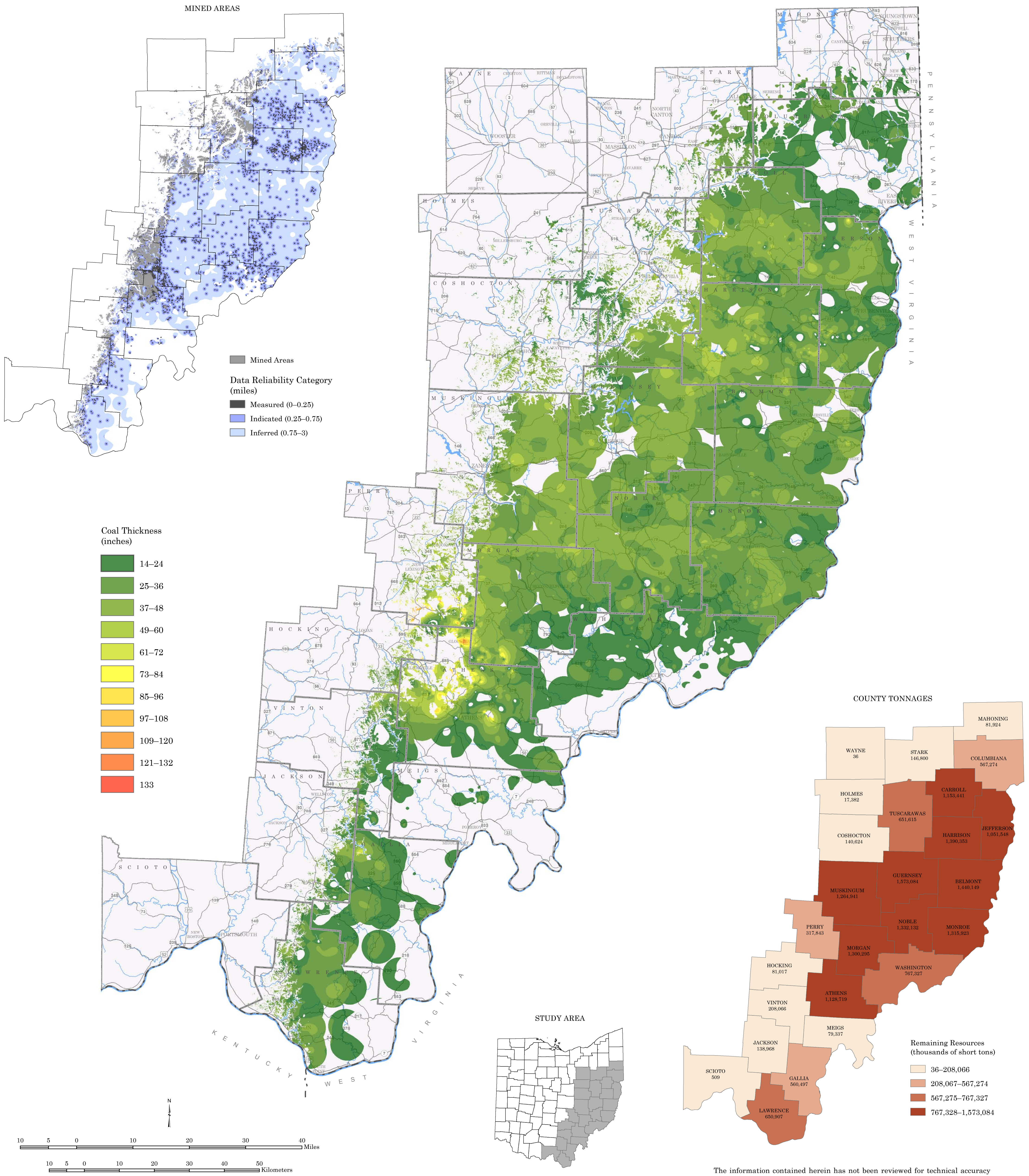


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REMAINING RESOURCES ISOPACH OF THE MIDDLE KITTANNING (NO. 6) COAL BED IN OHIO

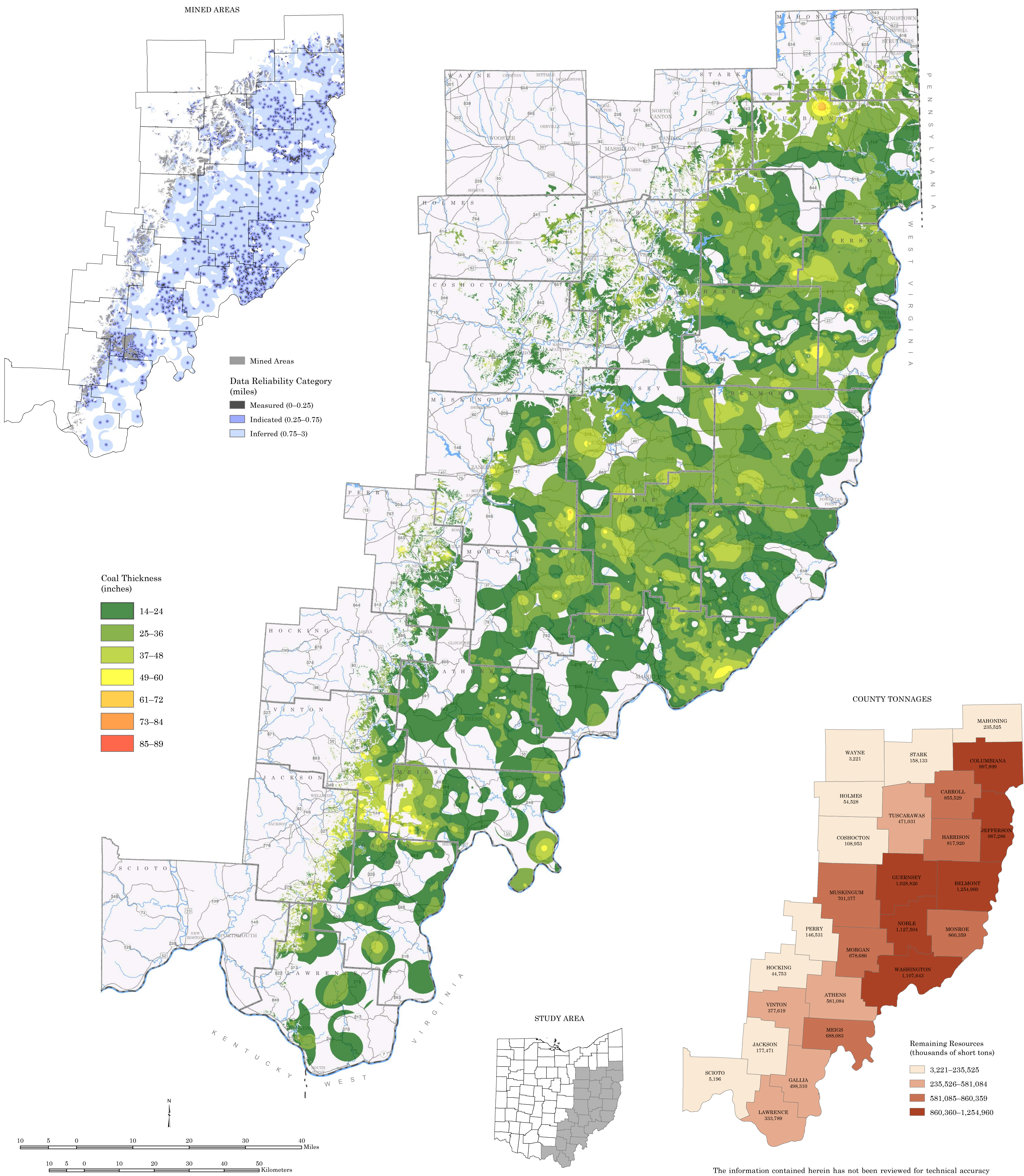
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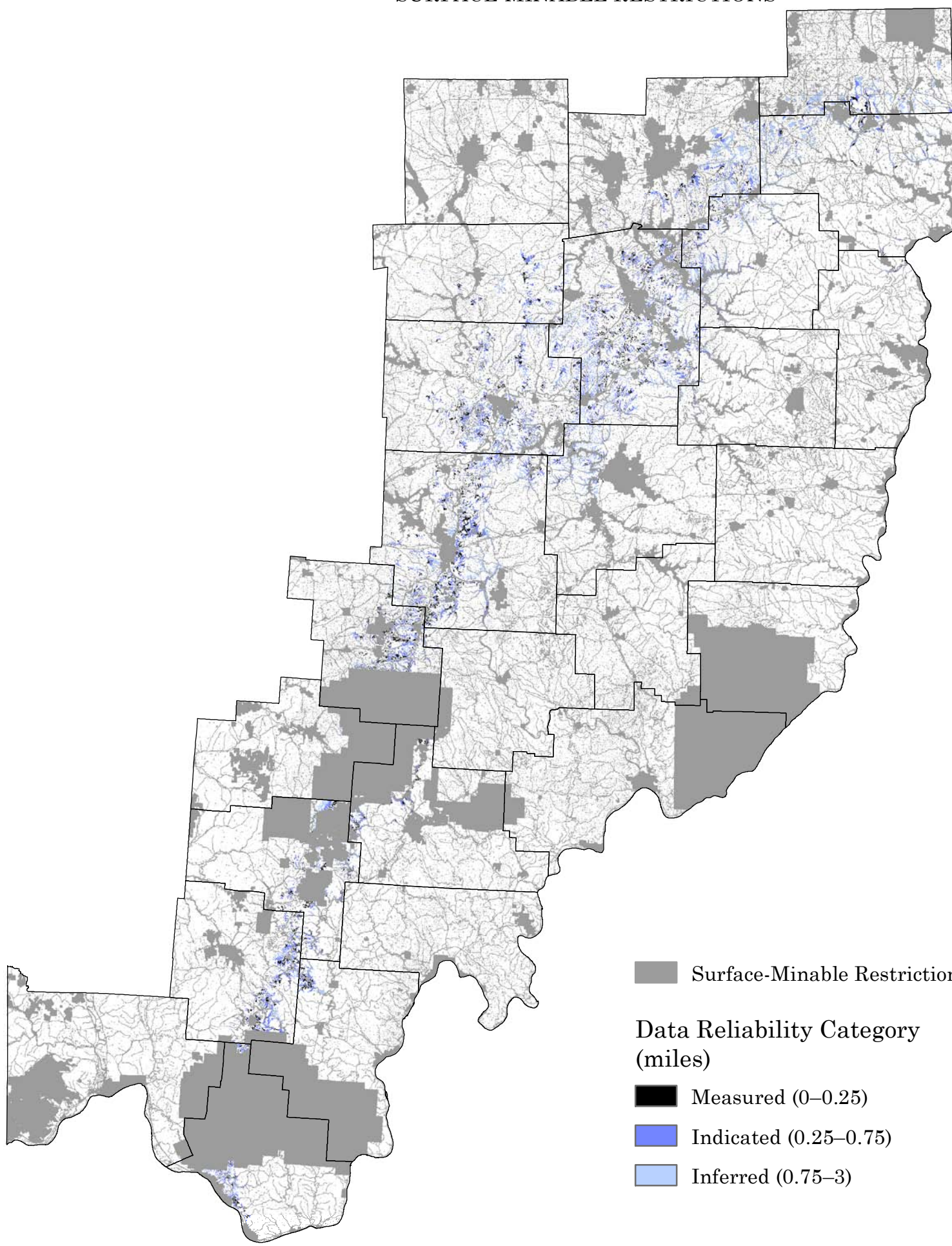


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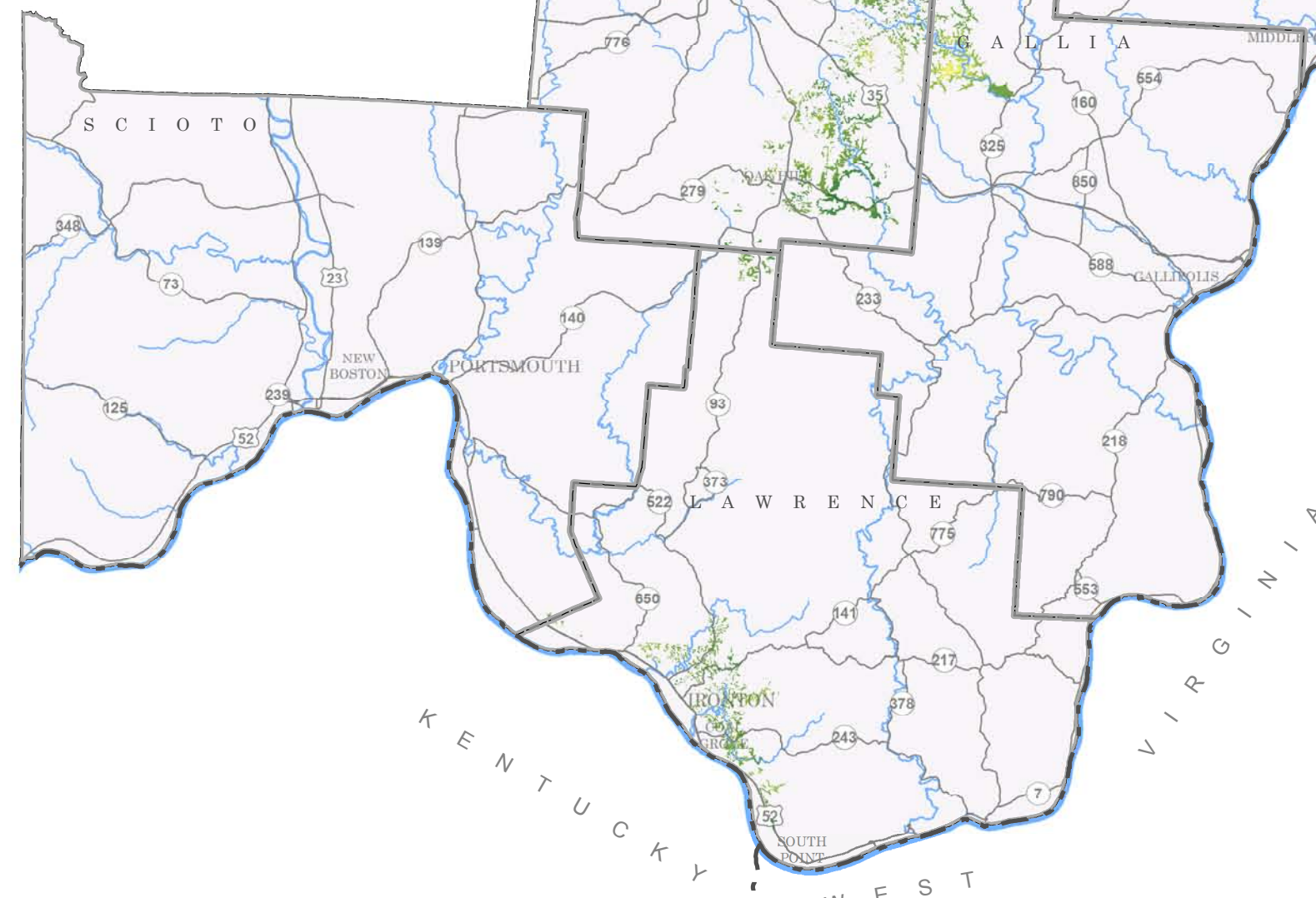
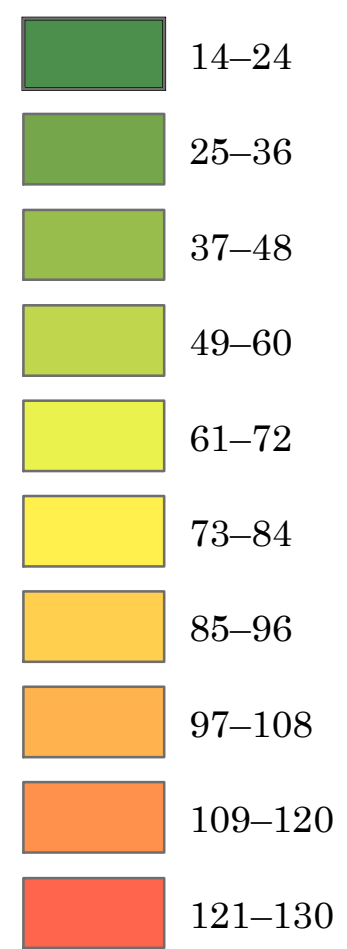


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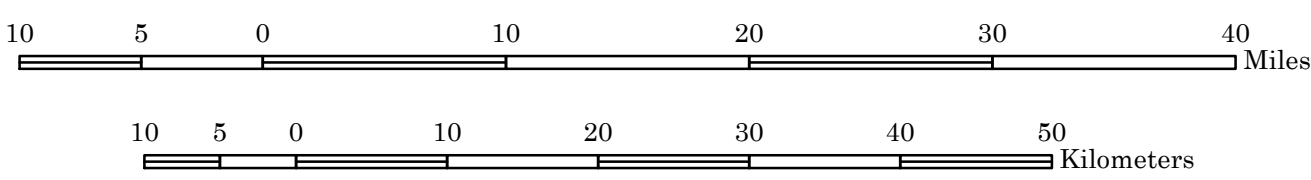
SURFACE-MINABLE RESTRICTIONS



Coal Thickness (inches)

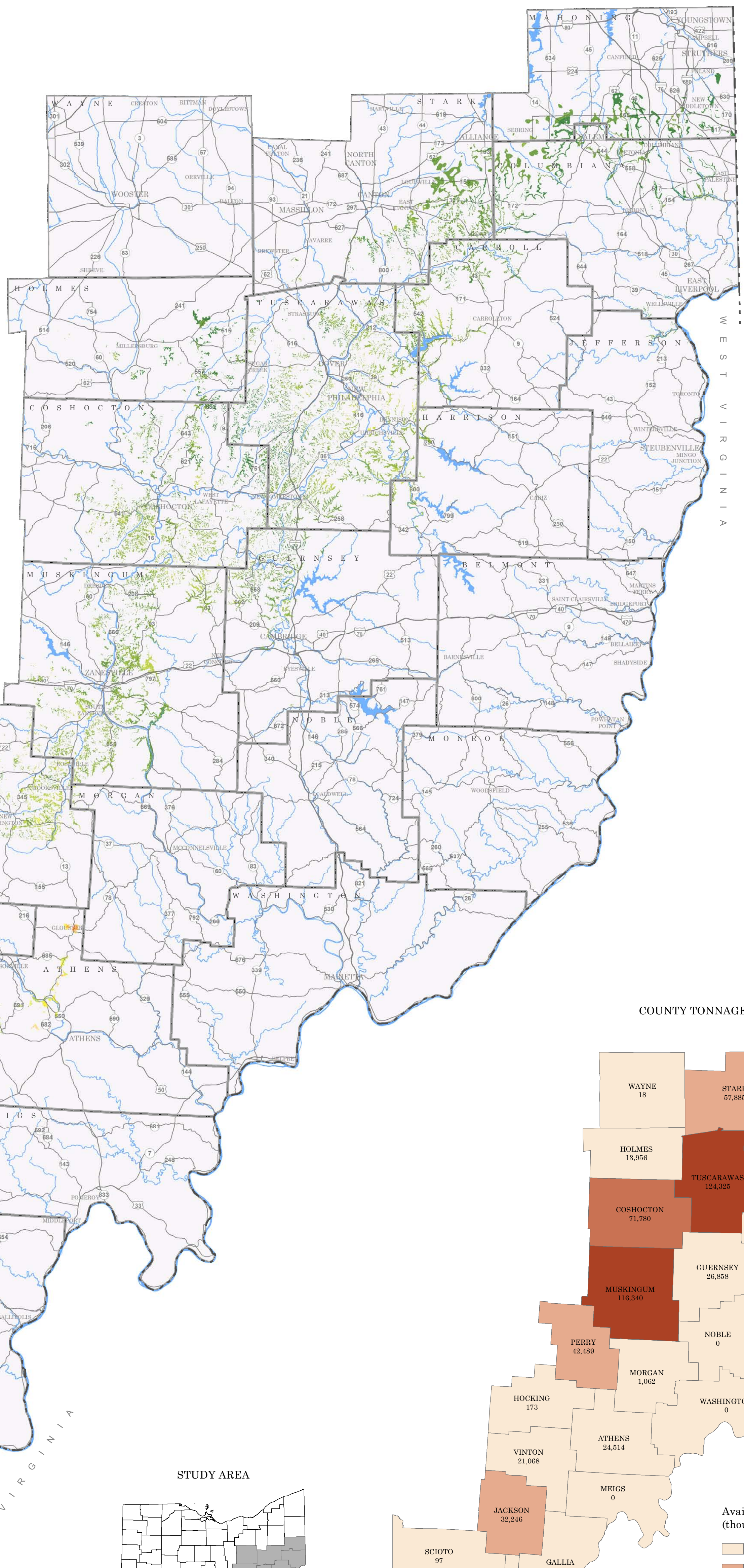


STUDY AREA

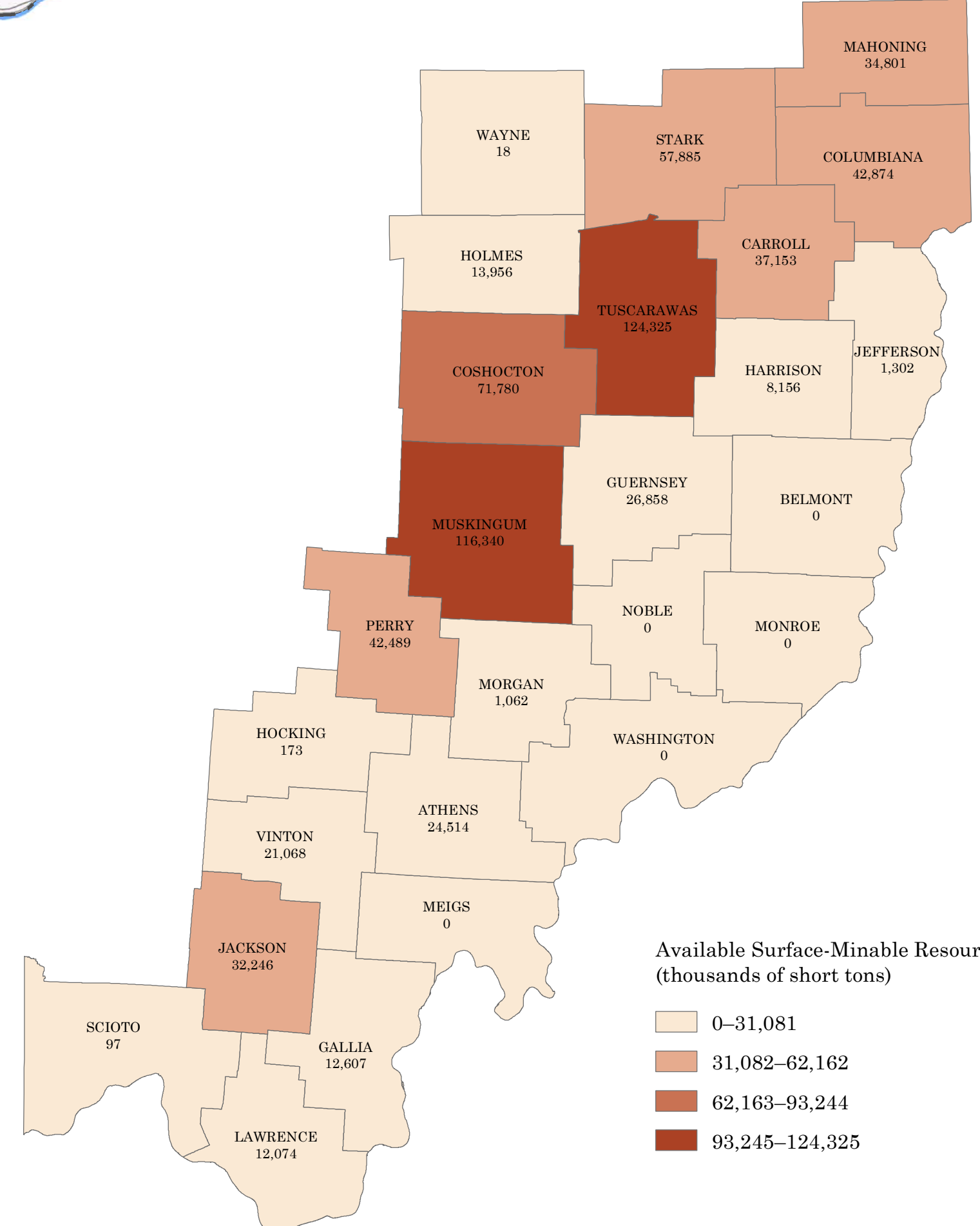


SCALE 1:500,000

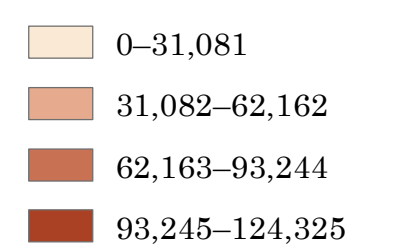
Projection is Ohio coordinate system, south zone, North American Datum 1983.



COUNTY TONNAGES



Available Surface-Minable Resources (thousands of short tons)

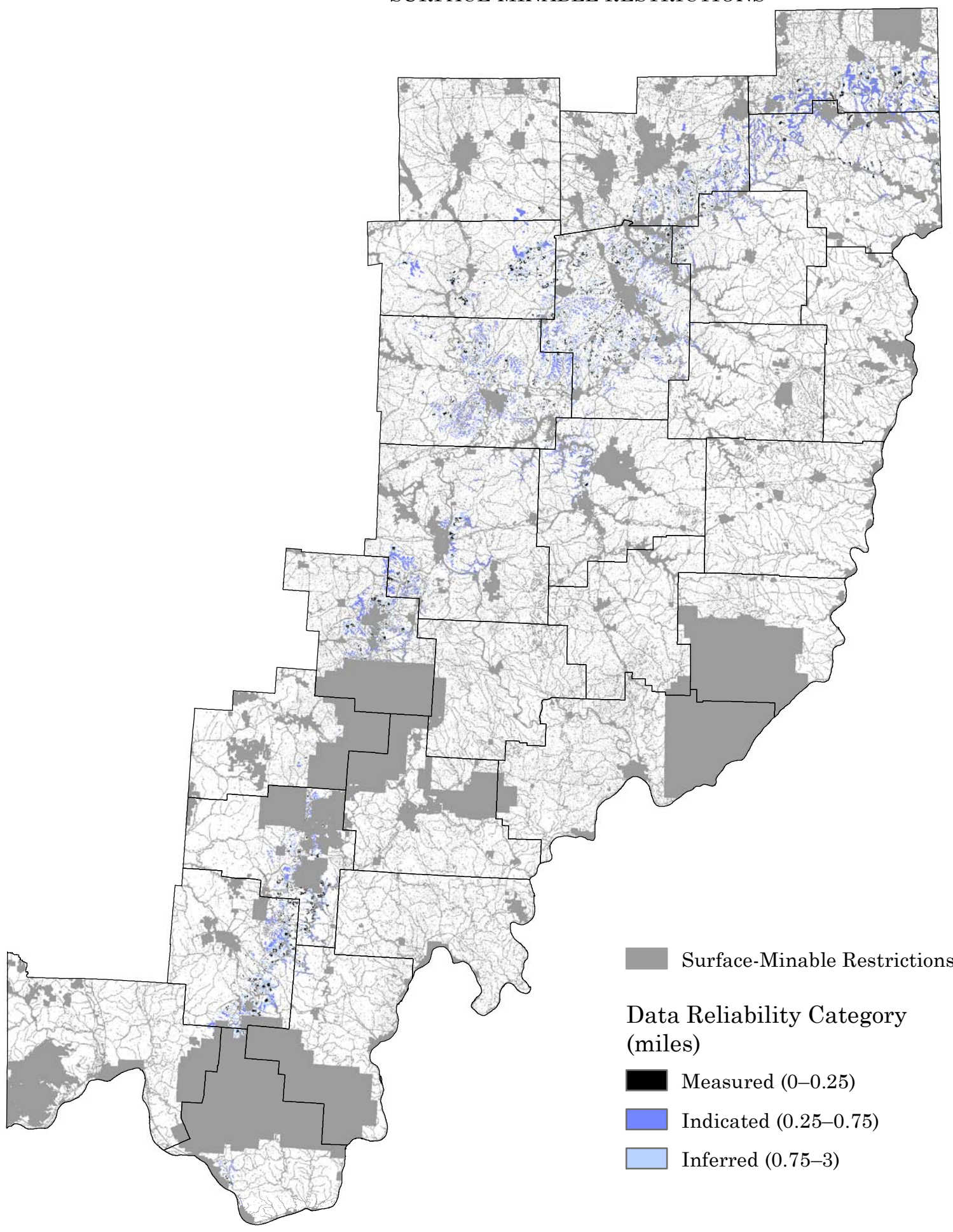


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SURFACE-MINABLE RESTRICTIONS

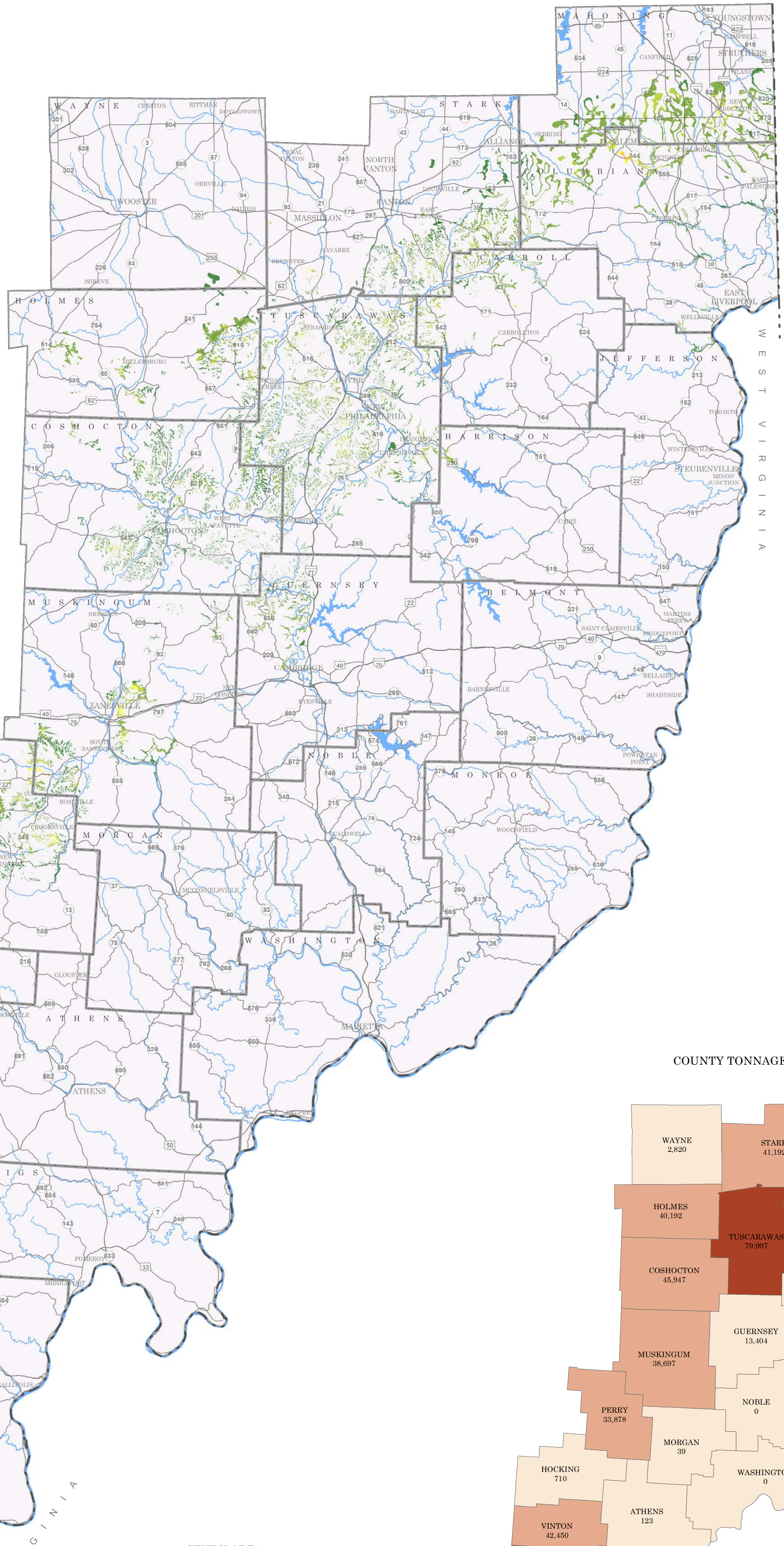
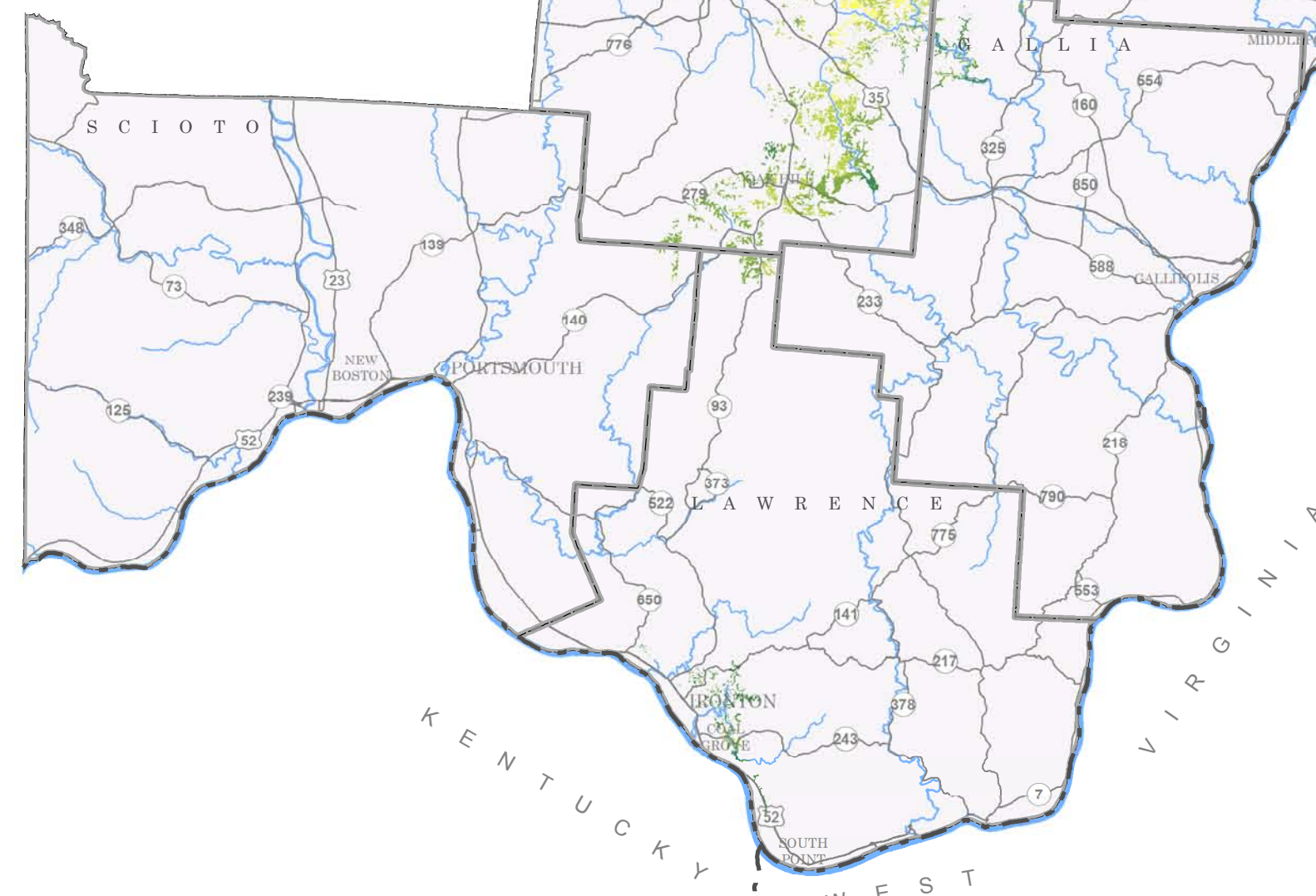
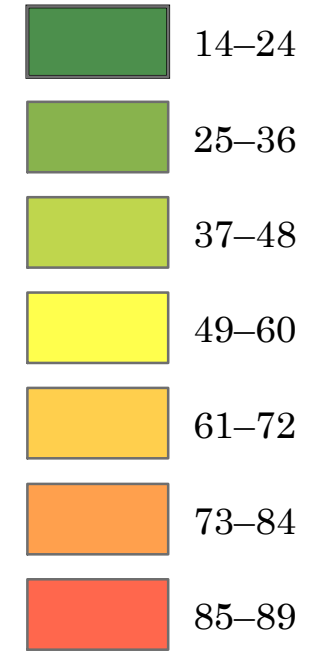


■ Surface-Minable Restrictions

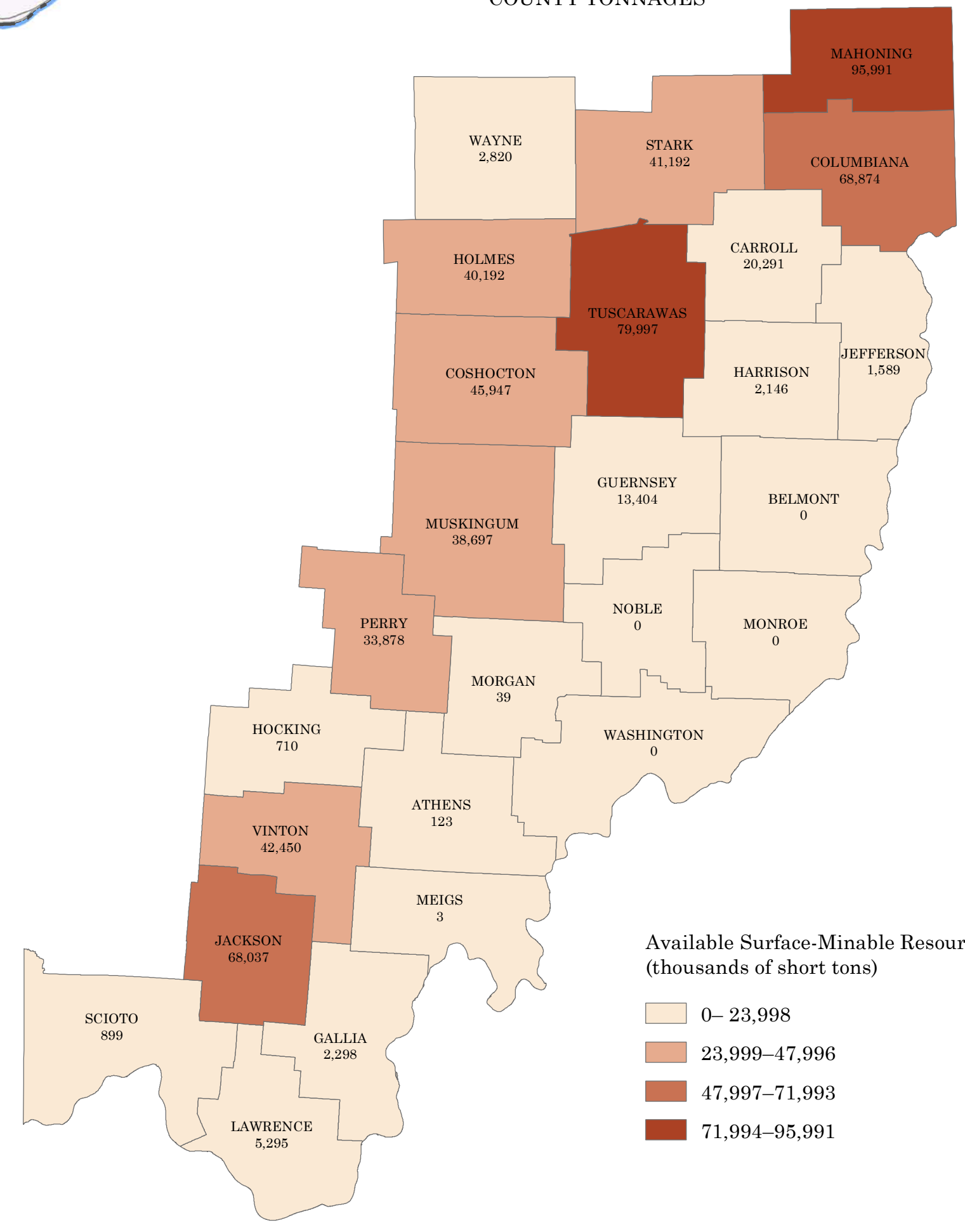
Data Reliability Category (miles)

- Measured (0–0.25)
- Indicated (0.25–0.75)
- Inferred (0.75–3)

Coal Thickness (inches)



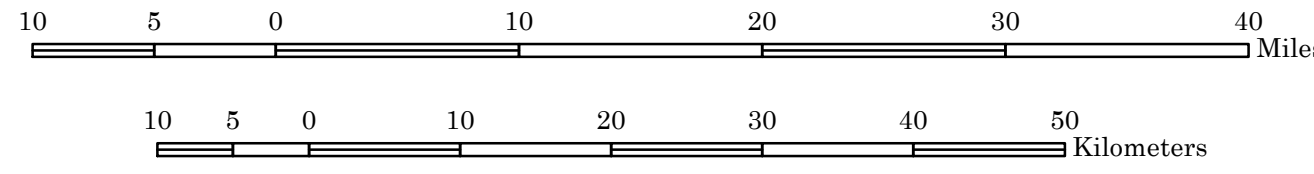
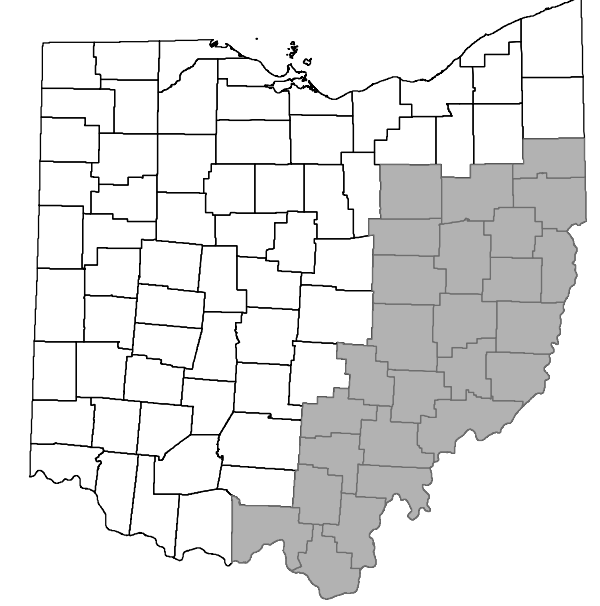
COUNTY TONNAGES



Available Surface-Minable Resources (thousands of short tons)

- 0–23,998
- 23,999–47,996
- 47,997–71,993
- 71,994–95,991

STUDY AREA



SCALE 1:500,000

Projection is Ohio coordinate system, south zone, North American Datum 1983.

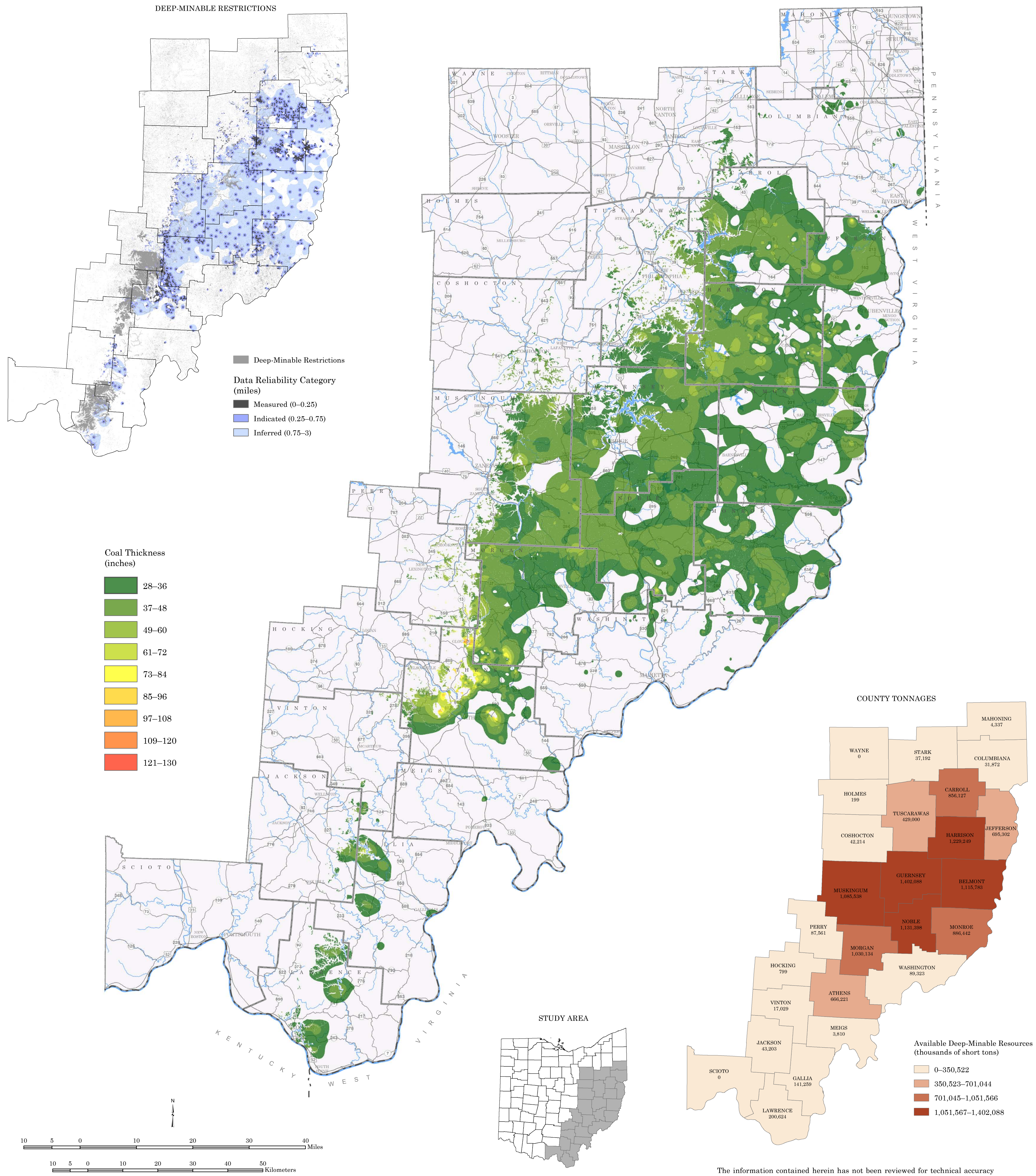


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AVAILABLE DEEP-MINABLE RESOURCES ISOPACH OF THE
MIDDLE KITTANNING (NO. 6) COAL BED IN OHIO

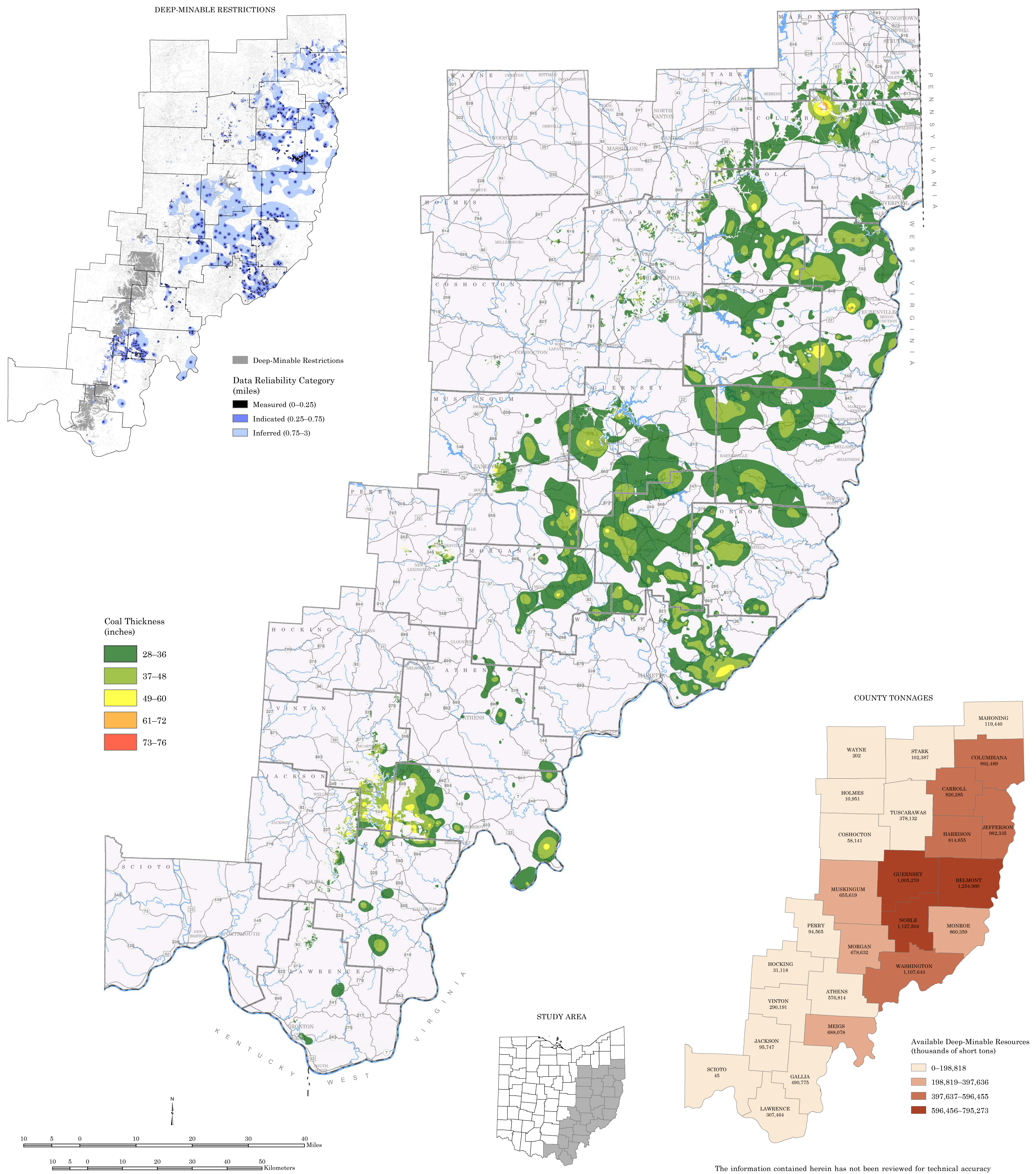
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