

A topographic map of a region in Ohio, showing terrain contours, rivers, and roads. The map is overlaid with a large black rectangular border. The text is centered on the map. The background shows various shades of green and brown, indicating elevation and vegetation. Major roads are marked with numbers in circles or squares. The names of counties and towns are visible in a light font.

# **Evaluation of Available Resources of the Pittsburgh (No. 8) Coal Bed in Ohio**

by  
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&

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Open-File Report 2016-2  
Columbus 2016



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*Recommended citation:* Sorrell, L.M., and Spahr, P.N., 2016, Evaluation of available resources of the Pittsburgh (No. 8) coal bed in Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Open-File Report 2016-2, 22 p., 5 plates.

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## **ABBREVIATIONS USED IN THIS REPORT**

### ***Units of Measure***

British Thermal Unit .....	BTU
Foot/feet .....	ft
Inch(es) .....	in
Square foot/feet.....	ft <sup>2</sup>
Square mile(s) .....	mi <sup>2</sup>

### ***Other***

Digital elevation model .....	DEM
Geographical Information System .....	GIS
Mean sea level.....	m.s.l.

# Evaluation of Available Resources of the Pittsburgh (No. 8) Coal Bed in Ohio

by Lee M. Sorrell & Paul N. Spahr

## ABSTRACT

The Ohio Department of Natural Resources (ODNR), Division of Geological Survey (Ohio Geological Survey) performed an estimation of the remaining and available resources of the Pittsburgh (No. 8) coal bed in Ohio. This study represents the first statewide estimation of Pittsburgh coal resources in 14 years. The Pittsburgh (No. 8) coal is the most heavily mined coal bed in Ohio, representing 64 percent of the total coal mined within the state. Data points were collected to create base-elevation structure and isopach maps using Geographic Information Systems (GIS) technology. The base elevation structure raster was constructed from 47,714 data points using the Natural Neighbor interpolation technique. Sequential Gaussian simulation was used to create isopach maps from 2,725 data points, which were then summarized by county to obtain coal tonnages. Project results reveal that the Pittsburgh (No. 8) coal bed had an estimated 7.9 billion short tons of coal in Ohio before mining. Of that amount, 3.4 billion short tons have been mined and approximately 4.5 billion short tons remain. Of the remaining resources, 348 million short tons are available for surface mining and 2.6 billion short tons are available for underground mining. The majority of the available resources exist in Belmont County (777 million short tons) and Monroe County (1.1 billion short tons). Given that the current rate of mining for the Pittsburgh (No. 8) coal is 14 million short tons per year, these resources will last for more than a century.

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## INTRODUCTION

Coal mined in Ohio is a significant natural resource that is of value not only to the economy and energy production in Ohio but also to the nation. Nationally, Ohio ranks eleventh in coal production with 22 million short tons produced in 2014 (Stucker, 2015). Ohio has 67 named coal beds with 24 coal beds containing minable resources (Brant and DeLong, 1960). During 2014, 15 named coal beds were mined (Stucker, 2015). Coal is the third largest mineral-extraction industry in Ohio and represents 20 percent of the total value of fuel and non-fuel extractive industries, contributing annual revenues of \$1.1 billion to the Ohio economy (Stucker, 2015).

Coal deposits were first described in Ohio during the 1740's and first mapped in 1752 (Crowell, 1995). Coal mining in Ohio began in 1795 (Bownocker and Dean, 1929). Coal was first used to heat homes as a cheaper alternative to wood. In 1809, a cord of wood cost two dollars, while a bushel of coal cost only six cents (Tewalt and others, 2001). Coal use has evolved from its first use as heating fuel to fuel for railroad steam engines and steel creation during the mid-nineteenth century. Now, over ninety percent of coal in the United States is used for electrical generation (IER, 2015). Sixty-seven percent of the electricity used by Ohioans is generated by coal-burning power plants (EIA, 2015).

More coal has been mined from the Pittsburgh coal bed than from any other coal bed in the Appalachian

Basin (Ruppert, 2001). As such, it has had great economic value to both Ohio and the nation during the past two hundred years. Ohio, West Virginia, Pennsylvania, and Maryland are the four states containing the Pittsburgh coal bed within the Appalachian Basin.

A number of regional to semi-regional resource studies of the Pittsburgh coal bed in Ohio have been conducted in the past (Clark, 1917; Ray, 1929; Smith, 1952; DeLong, 1955; Brant and DeLong, 1960; Couchot, 1978; Carlton, 1991; Tewalt and others, 2001). Axon (1996) performed a resource estimate of the coal beds in the Bethesda quadrangle located in Belmont County.

Outdated resource estimates present a problem for the coal industry when planning and targeting new areas for mining. The last statewide resource assessment of the Pittsburgh coal was published in 2001 (Tewalt and others, 2001). Since that time, large amounts of data from current and historical mining have accumulated, and techniques for resource estimation have evolved and improved. Where resource estimates once had necessitated extensive field work, today's techniques utilize digital orthophoto and LiDAR datasets, GIS, and computer processing techniques that improve the accuracy and speed with which resource estimates can be performed. The objective of this study was to determine the amount and location(s) of coal currently remaining and available for mining in the Pittsburgh (No. 8) coal bed within Ohio.

## GENERAL GEOLOGY OF THE PITTSBURGH (NO. 8) COAL BED

Within the Appalachian Basin, the Pittsburgh coal bed extends from northwestern West Virginia to southeastern Pennsylvania (fig. 1). The Pittsburgh coal bed extends over 5,000 mi<sup>2</sup> throughout four states, reaching its thickest point in Maryland. The Pittsburgh coal bed lies at the base of the Monongahela Group in the Pennsylvanian System (fig. 2). The Conemaugh Group directly underlies the Pittsburgh coal. Two cross sections along strike and two along dip were created to assist in characterizing the general geology. Lithologies in the cross sections were combined into one of six lithologic groups (figs. 3, 4, 5, and 6).

Because of subsidence in the Appalachian Basin during deposition, the Monongahela Group thickens to the east from 200 feet (ft) in Ohio to 430 ft in north-central West Virginia (Tewalt and others, 2001). In Ohio, the regional dip is to the southeast at approximately 30 ft per mi. The Monongahela Group in Ohio

is made up of freshwater strata, bearing no record of a marine transgression (Stout, 1954). The strata consist of cyclic deposits of coal, sandstone, shale, freshwater limestone, and clay. The majority of the limestones and shales are calcareous. Monongahela Group clays generally are thin compared to lower Pennsylvanian strata, such as the Conemaugh and Allegheny Groups, where the clays are much thicker. Sandstones occur throughout the section and are frequently positioned on top of coal beds (Stout, 1954). Channel sandstones often migrate and replace the Pittsburgh coal locally.

A total of eight coal beds, both economic and non-economic, exist in the Monongahela Group. The Pittsburgh coal bed is the most extensive and thickest coal of the Monongahela Group in the Appalachian Basin. DeLong (1955) divided the Pittsburgh coal bed into five major fields: the Belmont field, the Federal Creek field, the Eastern Washington field, the Shade Creek field, and the Gallia field (fig. 7). The Pittsburgh coal bed was mined and known by several names in Ohio

before being recognized and correlated as the Pittsburgh coal. In the Eastern Washington coal field, the Pittsburgh was called the "Lower Salem," and in the fields south of the Eastern Washington coal field, it was often confused with the Pomeroy (No. 8a, Redstone) coal bed (DeLong, 1955).

The Pittsburgh coal bed in Ohio varies in thickness from 0 to 176 inches. The thickness of the Pittsburgh coal bed in Belmont County is approximately 50–60 in. When present, the roof coal is left *in situ* to seal the overlying strata from the humidity of the mine. Roof coal of greater than a foot is preferred (William Siplivy, written commun., 2015). Roof coal is not included in the resource calculations because it is used to protect the roof and is not mined.

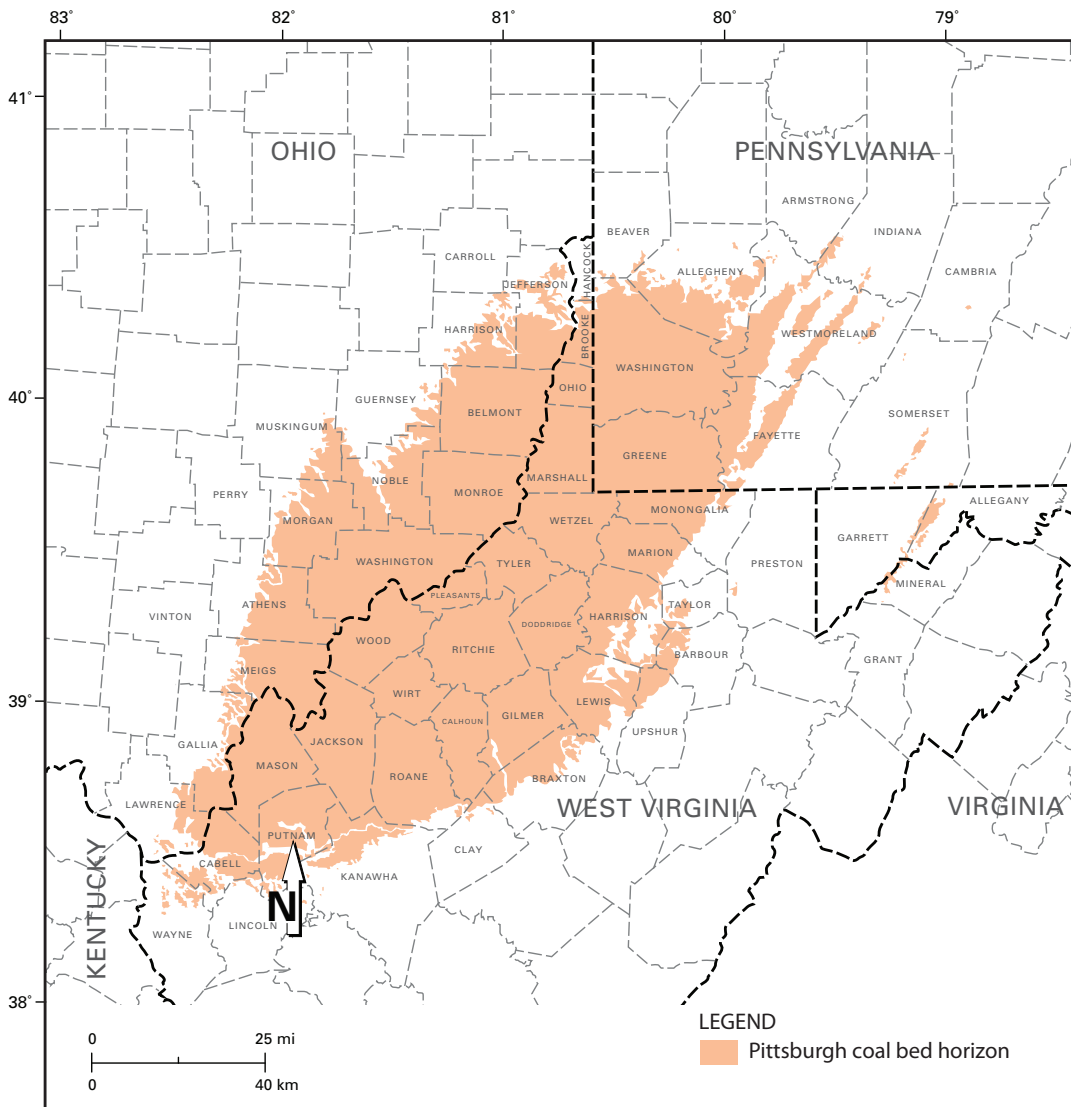
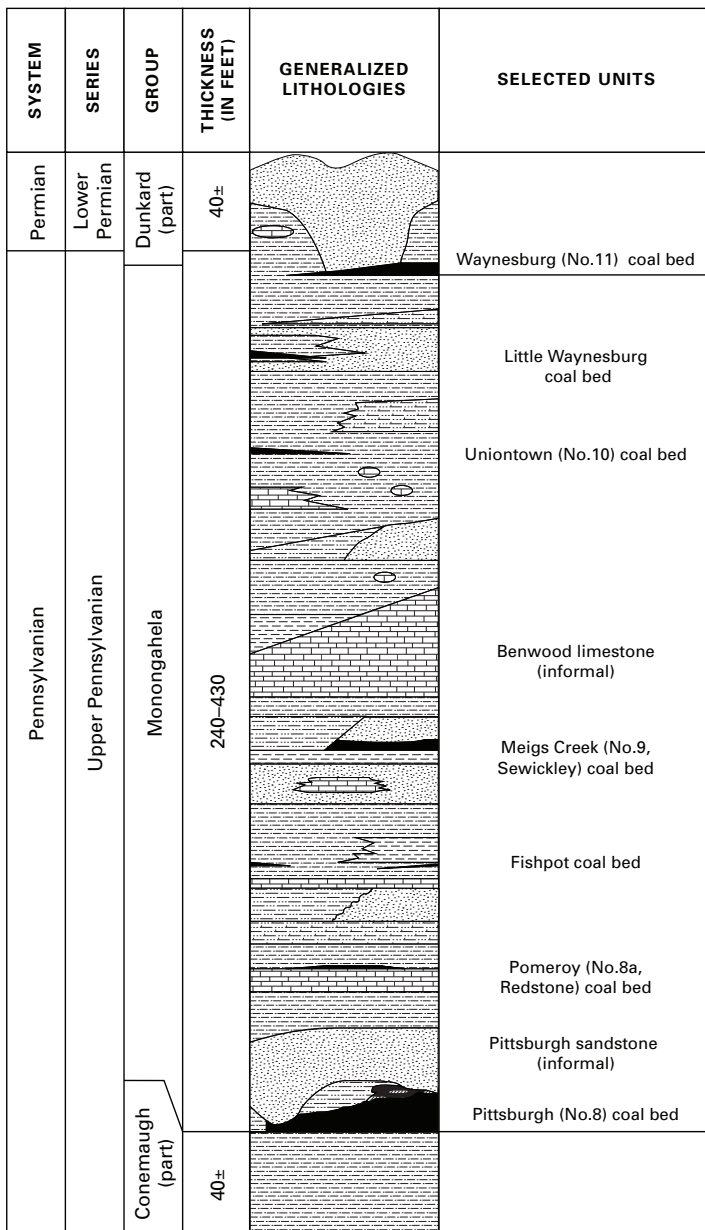


FIGURE 1. Areal extent of the Pittsburgh (No. 8) coal bed horizon, including both the Pittsburgh coal bed and other geologically equivalent strata (modified from Tewalt and others, 2001, fig. 2).



**LEGEND**

	Sandstone		Siltstone
	Limestone		Claystone
	Shale and siltstone		Coal
	Shale		Coal, or coal and shale

**FIGURE 2. Generalized stratigraphic column of the Monongahela Group in Ohio (modified from Tewalt and others, 2001, fig. 3).**

The elevation of the Pittsburgh coal bed in Ohio varies from 184 to 1,312 ft above mean sea level (m.s.l.). The majority of the Belmont coal field sits at 600 to 1,000 ft above m.s.l.

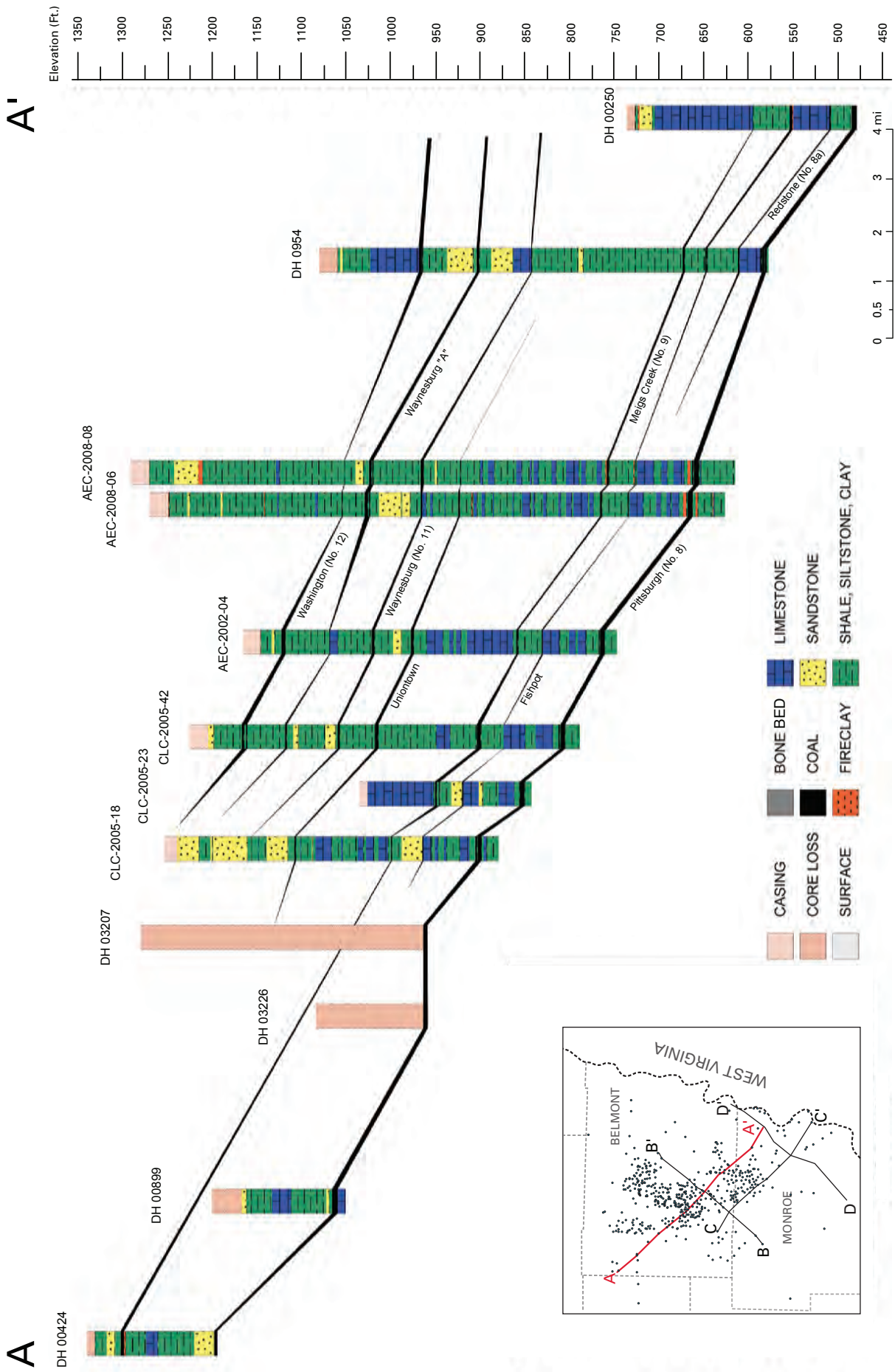
In most areas where the Pittsburgh is mined, the character and thickness of the Pittsburgh coal is remarkably consistent. The Pittsburgh coal is a high volatile “A” bituminous coal with medium ash and medium sulfur. Stout (1954) describes the general character of the Pittsburgh coal in Belmont County from top to bottom as follows:

- The roof rock varies between shale, sandstone, and limestone.
- Roof coal ranges from 0 to 30 in and is poor in quality (high sulfur and ash, low BTU).
- Clay-shale parting, “draw slate,” usually about 1 ft thick.
- Breast coal, a regular and valuable bench.
- Shale parting, regular, but usually quite thin.
- Bearing-in-coal, ordinarily less than 6 in thick, used for bearing-ins by the pick miners.
- Shale parting, regular, but generally thin.
- Brick coal, mining yields brick shaped blocks, good quality.
- Shale parting, regular, known as “copperband,” high in pyrite.
- Bottom coal, usually of inferior quality because of irregular partings.

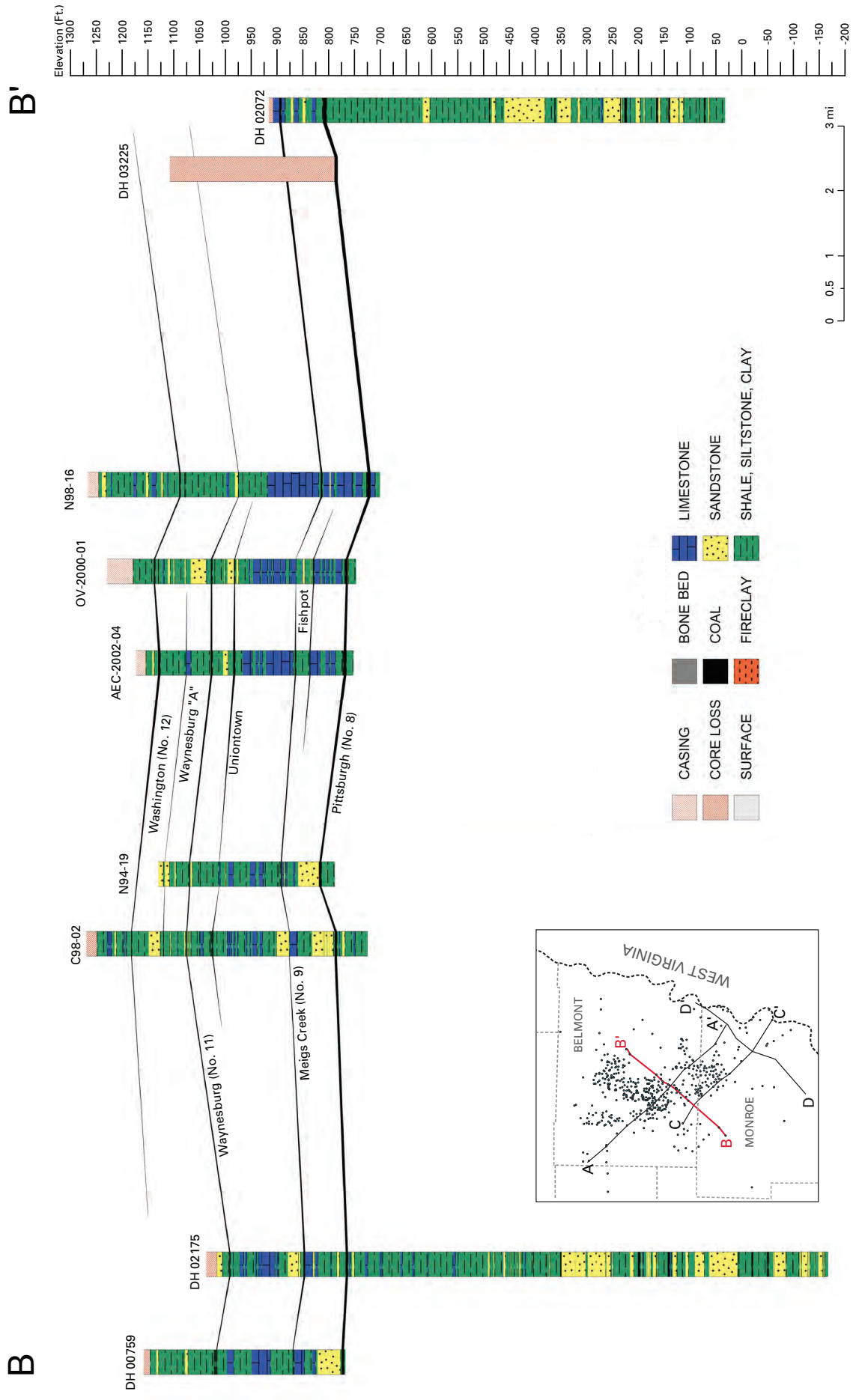
Where the coal is thin, it also displays a consistent character. The thin beds are typically owing to a lack of deposition instead of having been deposited and then subsequently eroded (Stout, 1954). Structural features that affect the Pittsburgh coal include the Cambridge Cross-Strike Structural Discontinuity in Guernsey, Noble, and Washington Counties; the Cadiz anticline in Harrison County, and the Jacobsburg anticline in Belmont County (fig. 8; DeLong, 1955).

**METHODOLOGY**

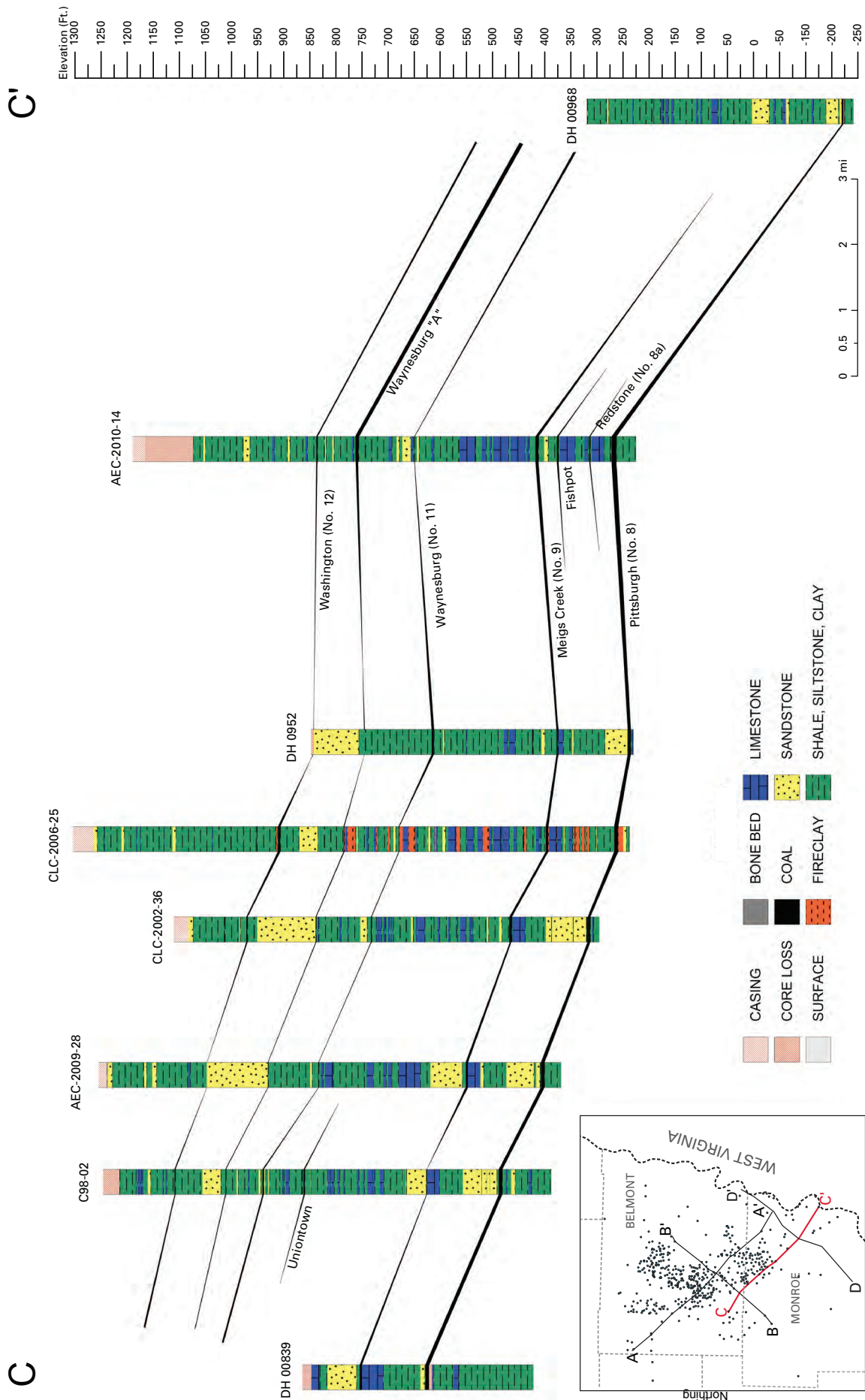
This investigation used the standard methodology developed by the United States Geological Survey (USGS) to assess coal resources (Wood and others, 1983; Olea and Luppens, 2014). Data points containing geographic coordinates, bottom coal elevations, and coal thicknesses for the Pittsburgh coal bed were compiled and entered into a database. These points were checked for spatial and stratigraphic accuracy and then interpolated to create a structure map of the base-elevation and a thickness (isopach) map for the Pittsburgh coal bed. The isopach map was used to calculate the original resources, which is defined as the amount of coal estimated to have been present prior to mining. For each coal bed, the areas containing re-



**FIGURE 3. Cross section A–A' through the Pennsylvanian-age rocks in Belmont and Monroe Counties, Ohio; note the regional dip to the southeast. Coal measures that pinch out are shown to disappear, while coal measures that are stratigraphically above the core are shown with square ends to denote the uncertainty in whether they pinch out or continue. Ohio Geological Survey core numbers are noted above the cores, some have not been given numerical identifiers and have the company names for the core listed.**



**FIGURE 4.** Cross section B-B' through the Pennsylvanian-age rocks in Belmont and Monroe Counties, Ohio; this cross section is the most northerly strike cross section. Coal measures that pinch out are shown to disappear, while coal measures that are stratigraphically above the next core are shown with square ends to denote the uncertainty in whether they pinch out or continue. Ohio Geological Survey core numbers are noted above the cores, some have not been given numerical identifiers and have the company names for the core listed.



**FIGURE 5.** Cross section C–C' through the Pennsylvanian-age rocks in Belmont and Monroe Counties, Ohio; note the regional dip to the southeast. Coal measures that pinch out are shown to disappear, while coal measures that are stratigraphically above the next core are shown with square ends to denote the uncertainty in whether they pinch out or continue. Ohio Geological Survey core numbers are noted above the cores, some have not been given numerical identifiers and have the company names for the core listed.

D

D'

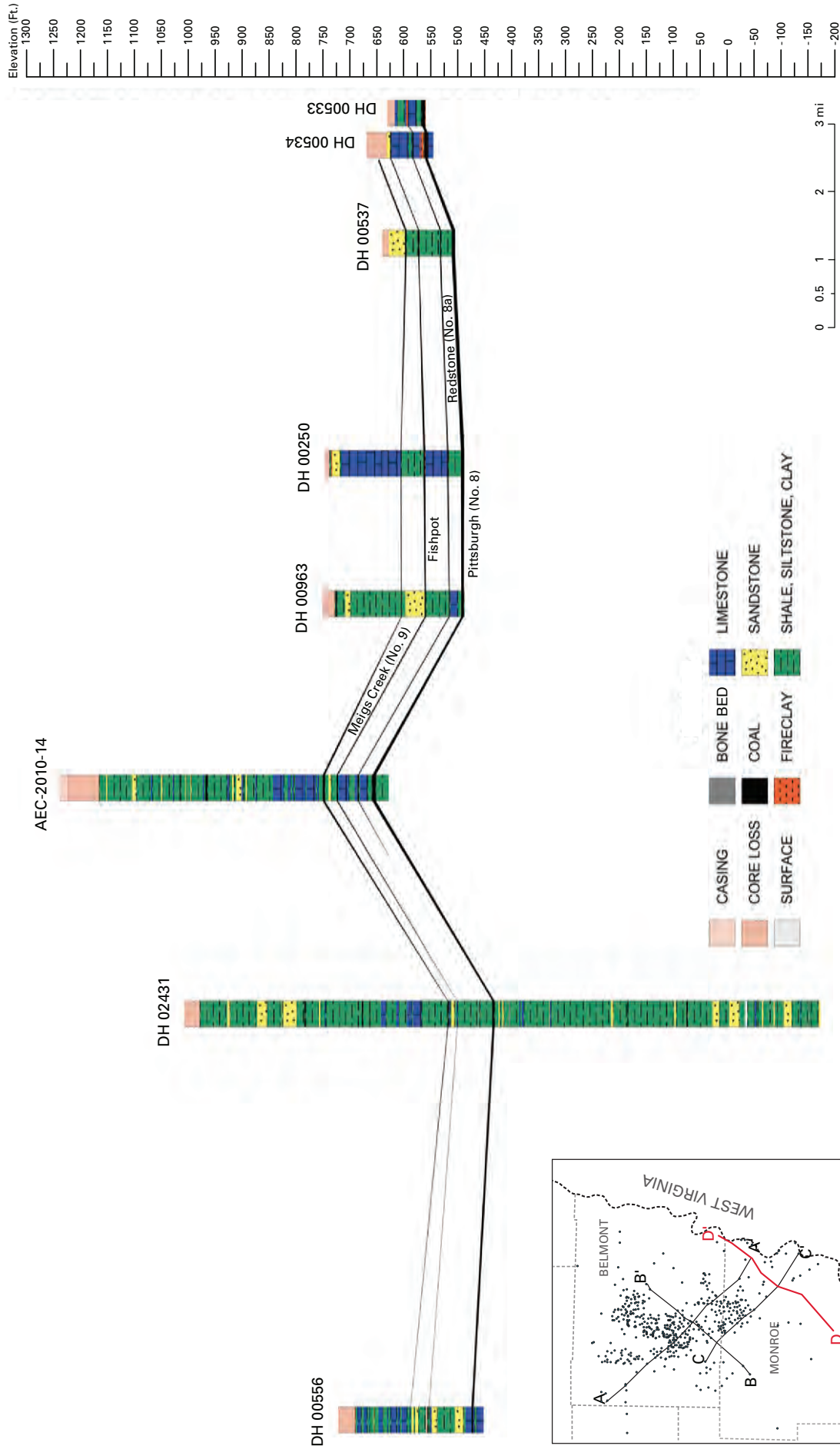


FIGURE 6. Cross section D–D' through the Pennsylvanian-age rocks in Belmont and Monroe Counties, Ohio; this cross section is the most southerly strike cross section. Coal measures that pinch out are shown to disappear, while coal measures that are stratigraphically above the next core are shown with square ends to denote the uncertainty in whether they pinch out or continue. Ohio Geological Survey core numbers are noted above the cores, some have not been given numerical identifiers and have the company names for the core listed..

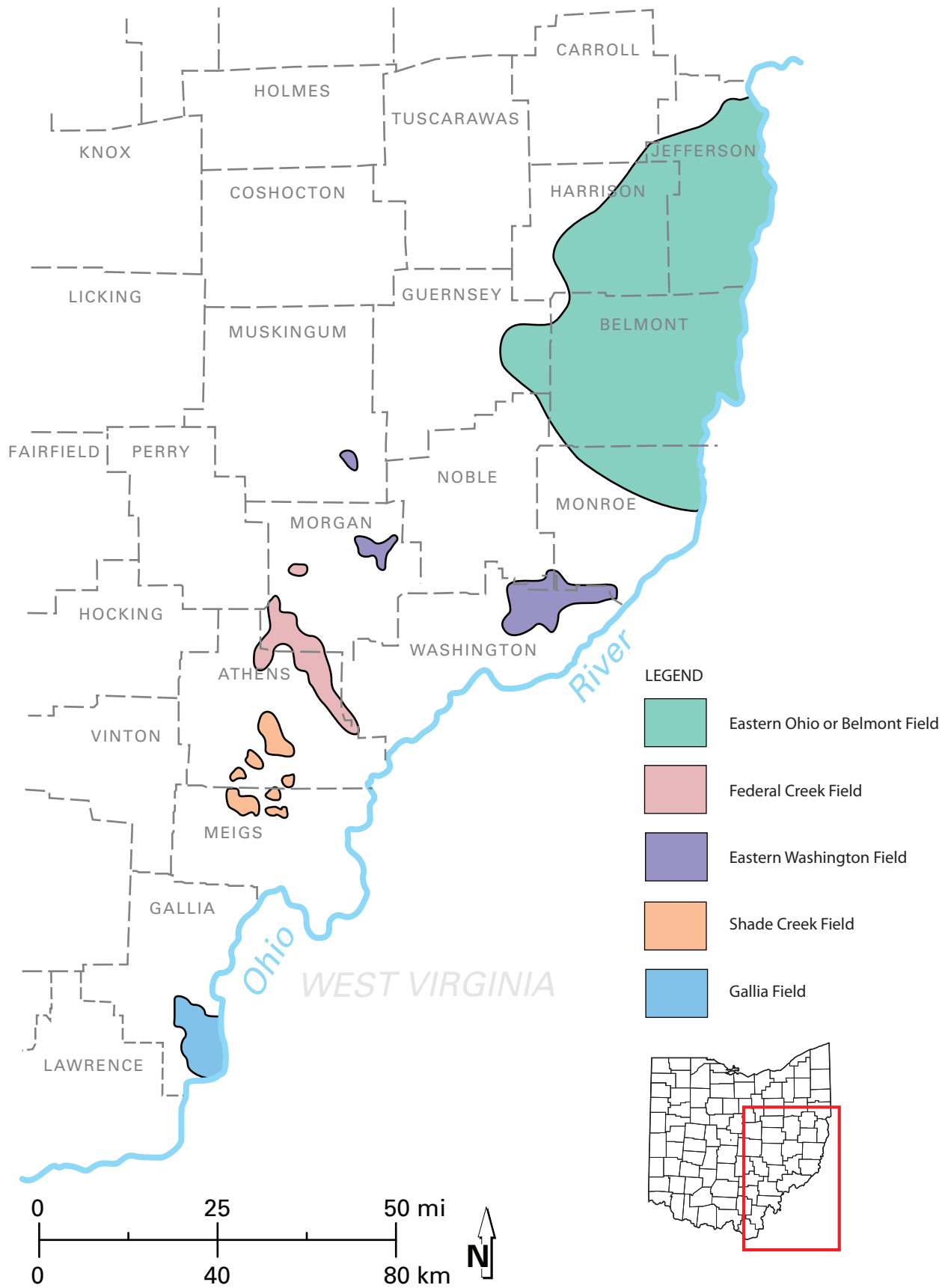
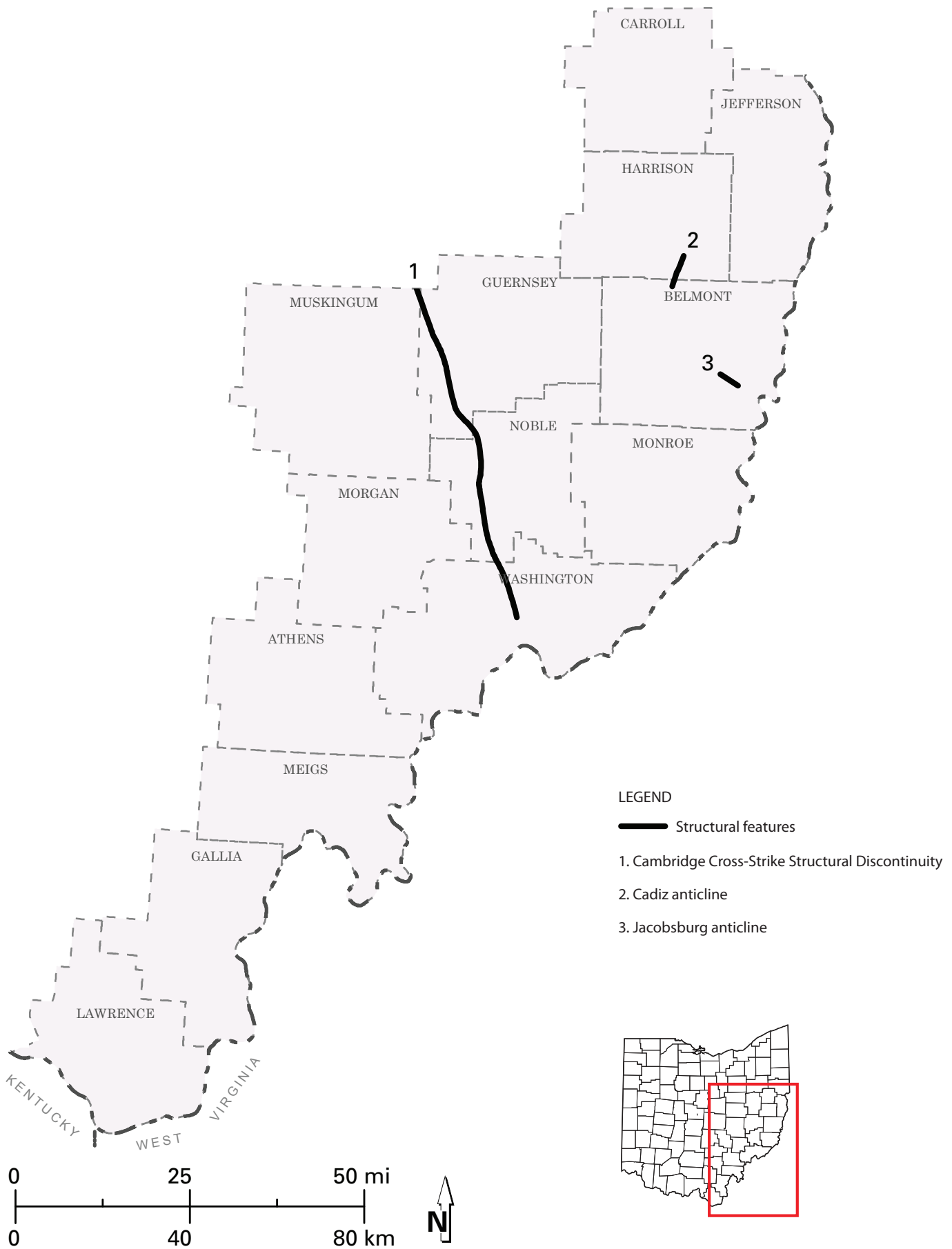


FIGURE 7. Distribution of Pittsburgh (No. 8) coal fields in Ohio (modified from DeLong, 1955, fig. 4).



**FIGURE 8. Structural features that affect the Pittsburgh (No. 8) coal bed in Ohio. Modified from Delong, (1955) and Baranoski (2013).**

maining resources were determined by subtracting the area of coal resources removed by surface and underground mining from the areas of original resources. Areas containing minable resources were calculated by subtracting the areas restricted by land-use and technological factors from areas containing remaining resources. The quantity of coal, summarized by county, was calculated for the original resources, remaining resources, and available resources for the Pittsburgh coal bed. Each step in the procedure is described in detail in the following paragraphs.

### **Data Collection**

Data points containing coal thickness and elevation of the bottom of the Pittsburgh coal bed were compiled from the USGS National Coal Resource Data System, which contains over 25,000 stratigraphic points for coal beds throughout Ohio and was the primary data source for resource calculations. Other data sources include information from oil-and-gas wells, Ohio Department of Transportation engineering bore logs, ODNR Division of Soil and Water Resources water well log records, previously measured sections, previously published and unpublished Ohio Geological Survey reports, current mine production information, and abandoned underground mine data obtained through the Ohio Mine Subsidence Insurance program.

After all of the data for the Pittsburgh coal bed were compiled into a database, each record was verified for spatial and vertical accuracy. The data were brought into GIS and displayed on a map to evaluate for flawed data. The data were assessed within GIS using a digital elevation model (DEM) to confirm that none of the data for the elevations of the coal beds were positioned at higher elevations than the land surface or located implausibly deep in the subsurface.

Miscorrelated points and data entry errors were discovered by (1) examining outliers of residuals from interpolation results and (2) comparing the stratigraphic position of the Pittsburgh coal bed relative to the overlying and underlying coal beds by an examination of raster surfaces.

The first method assessed the outliers of residuals from interpolation results. Raster surfaces of coal thickness and structure were created from the point dataset. Residual values for each point were calculated by subtracting the observed value from the predicted value. Positive residuals indicate where the predicted value of the data point was greater than the observed value of the data point. Negative residuals indicate where the predicted value of the data point was less than the observed value of the data point. The residual outliers (highest and lowest residual values) were inspected closely for miscorrelation or data entry errors. Points were removed from the dataset if several adja-

cent points showed a significant and consistent difference in residual values. The elevation of a coal bed should remain relatively consistent in a localized area while the thickness of a coal bed can vary dramatically over short distances because of the variability of the depositional environment in which the Pittsburgh coal was deposited. If there were no surrounding points for comparison, or other justifiable reasons to remove a point, the outlier was kept in the database.

The second method of detecting miscorrelated points and data entry errors was to create structure elevation maps to compare the stratigraphic position of the Pittsburgh coal bed relative to the overlying Pomeroy (No. 8a, Redstone) and Meigs Creek (No. 9) coal beds. If the Pittsburgh coal bed intersected either of the overlying surfaces, there were obvious correlation or data entry errors in the data used to create the surfaces. Several correlation errors were found and eliminated using this method.

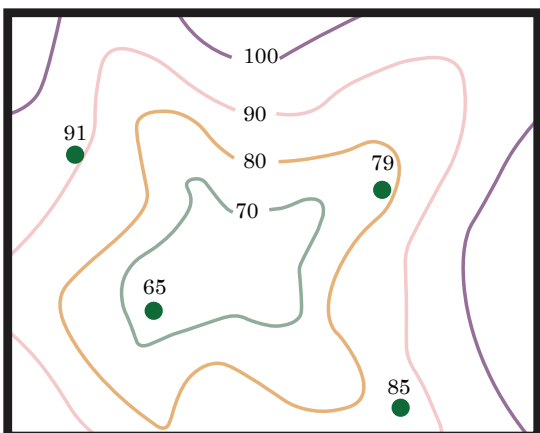
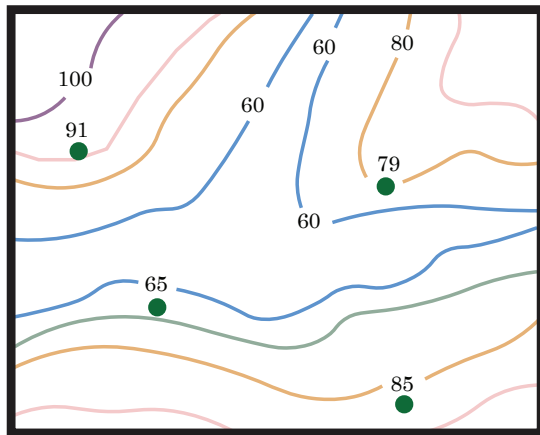
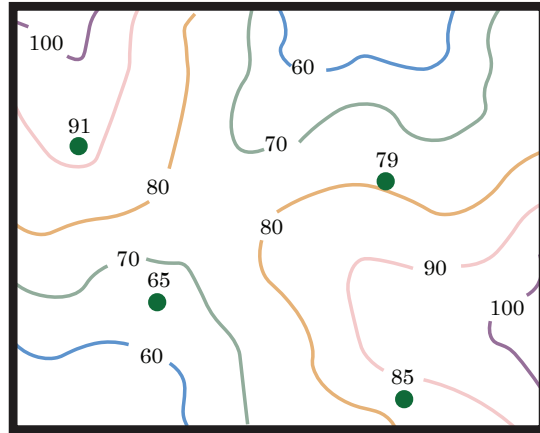
### **Map Creation**

#### *Structure map*

The base elevation structure raster was created in GIS using the Natural Neighbor interpolation technique. Natural Neighbor is an interpolation technique that uses Voronoi tessellation to assign weights to nearby points and interpolate values based on those weights (Hiyoshi, 2008); this is also known as a Sibson or “area stealing” approach to interpolation. Natural Neighbor interpolation is often used for data comprised of large, clustered-point datasets similar to the Pittsburgh coal bed dataset (Childs, 2004). This technique does not infer trends nor interpolate beyond the maximum and minimum data values and the areal extent of the data. The Natural Neighbor interpolation produced a continuous surface of estimations for the structure of the coal bed. The extent of the continuous surface estimation encompasses the extent of all data points used in the interpolation. Therefore, the extents of the structure map were clipped to the outcrop of the coal beds and state boundary. The outcrop of the coal bed was delineated by removing areas of the surface estimation that had higher elevations than the DEM.

#### *Original resources*

Original coal resources are defined as the amount of coal estimated to have been present prior to mining. Simulation methods for coal resource assessments have been widely studied (Heriawan and Koike, 2008; Olea and others, 2011; Bertoli and others, 2013; Cornah and others, 2013; de Souza and others, 2013; Ertunç and others, 2013; Geboy and others, 2013; Pardo-Igúzquiza and others, 2013; Saikia and Sarkar, 2013; Srivastava, 2013; Tercan and others, 2013; Tercan and Sohrabian, 2013; Webber and others, 2013; Olea and Luppens, 2014).



**FIGURE 9. Examples of three different but valid contour maps, all drawn from the same data (shown in the top image). Modified from Olea and others (2011).**

A sequential Gaussian simulation approach using ArcGIS Geostatistical Analyst was used to create the original resources isopach map in accordance with the current USGS methodology for estimating coal reserves (Olea and Luppens, 2014).

Sequential Gaussian simulation produces different but equally probable raster layers called *realizations* from the thickness data points using a simple kriging interpolation method. Each realization is a different representation of the coal bed created from the same data. Figure 9 is a conceptual diagram that illustrates different but plausible maps created from a small hypothetical data set. For this study, 200 realizations were created for the thickness of the Pittsburgh coal bed. Each realization was created at a 500-ft raster cell grid size, the smallest spacing that ArcGIS could process because of the sizable extent of the dataset.

To determine cells that had less than a 15 percent probability of coal presence, a single realization was created using indicator kriging. These cells were removed from the original resource estimation. A single realization was created for this study because ArcGIS does not support sequential indicator simulation. This methodology diverges from Olea and others (2011) where multiple indicator kriging realizations are performed to determine the probability of coal presence.

The data distributions of the output of the 200 realizations were summarized on a per-cell basis to create rasters that represent the distribution of the estimation. For this study, output rasters, based on the distribution of values at each cell, include the 5th, 25th, 50th (median), 75th, and 95th percentiles. In this report, the median values are reported for the resource estimation. However, the appendix contains charts and tables of the distribution values summarized by county.

The next procedure took the 500-ft grid raster layers that represent the distribution of the estimation and resampled them to a 100-ft cell size. This was necessary for removing land-use restrictions to estimate the available resource maps (as described in the following section). For example, oil-and-gas wells are required, by law, to have a 100-ft buffer around them in areas where the well penetrates a coal bed. Therefore, any cell that contains an oil-and-gas well is removed from the estimation. If the cell size of the estimation rasters were retained at 500 ft, a greater volume of coal would be removed from the estimation than compared to a 100-ft cell size.

The final procedure in creating the original resource isopach map was to remove specific areas from the original resources raster layer. First, areas in which the coal bed was less than 14 in thick were not considered a resource and were removed from the

thickness map. Secondly, areas considered “hypothetical” by the Coal Resource Classification System of the USGS were removed from the thickness maps (Wood and others, 1983). Areas are classified as hypothetical where beds are located beyond a 3-mi radius from a thickness data-point measurement. Very few areas in the study area were excluded because of a lack of data, as most areas have at least one data point within a 3-mi radius; this was also a deviation from the methodology of Olea and Luppens (2014). Finally, the original resource isopach grids were clipped to the state boundary and outcrop extent based on the DEM.

**Remaining resources**

For the Pittsburgh coal bed, areas containing remaining resources were determined by subtracting areas of coal resources removed by surface and underground mining from areas of original resources. Using the abandoned underground mine and surface mine GIS datasets, the mined-out coal is removed from the original coal resource estimate to arrive at an *in-situ* resource estimate.

Two GIS layers, created by the ODNR Division of Mineral Resources Management, were used to delineate areas where the coal has been removed through surface mining. The first GIS layer portrays all of the recently permitted and documented surface mines. The second layer depicts all surface mine disturbances, shown on historic topographic maps, that were mined before documentation and permitting was required for surface mines.

GIS layers showing abandoned underground mines, created by the Ohio Geological Survey as part of a study for the Ohio Mine Subsidence Insurance Underwriting Association, were used to remove areas from the original resources where the coal was removed through deep-underground mining.

The remaining resources for the Pittsburgh coal were divided into remaining surface-minable coal and remaining deep-minable coal. To make this determination, a 20:1 overburden-to-coal thickness ratio was used as an indicator of the economic feasibility of surface mining or underground mining. Base structure maps of the coal beds and the DEM were used to create a 20:1 overburden-to-coal thickness delineation. Regions of remaining resources located in areas where the overburden was less than 20:1 were classified as surface minable, and areas greater than 20:1 were classified as deep minable.

**Available resources**

Areas containing available resources were determined by subtracting the areas restricted by land-use and technological factors from areas containing remaining resources; this method is based on the work

of Eggleston and others (1990) and Axon (1996). Land-use restrictions affected the availability of surface-minable coal, and technological restrictions affected deep-minable coal. Oil-and-gas wells affected both surface- and deep-minable coal. Buffers around the restrictions ensure that the restricted features are protected from potential damage that could result from mining activities (table 1).

GIS layers depicting restricted areas for surface- and deep-minable coal were created. Most maps that show restriction classifications came from existing GIS layers from the State of Ohio databases; exceptions include airports, wetlands, streams, and coal less than 28 in thick. Airports were digitized from topographic maps. Wetland polygons were taken from the National Wetlands Inventory compiled by the U.S. Fish and Wildlife Service. Stream maps came from the National Hydrography Dataset. The restriction for coals beds less than 28 in thick was derived from the remaining resources map created for this project.

To create the available resources map, the GIS restriction layers were buffered by their appropriate distances and the restrictions removed from the remaining resources layers.

**TABLE 1. Restrictions to mining and the amount of buffer required for each restriction**

Restriction	Buffer (ft)	Restriction Type		Type of Mining	
		Land use	Technological	Surface	Deep
Airports	100	•		•	
Cemeteries	300	•		•	
Roads	100	•		•	
Railroads	100	•		•	
Towns	0	•		•	
Streams	100	•		•	
State parks	0	•		•	
Oil-&-gas wells	100	•		•	•
Wetlands	0	•		•	
Mine barrier	100	•			•
Coal too thin (< 28 in)			•		•

### County resource calculations

The quantity of coal, summarized by county, was calculated for the original resources, remaining resources, and available resources for the Pittsburgh coal using the following formula:

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

where:

- $Q$  = quantity of coal in county (short tons)
- $S_c$  = sum of coal thickness in county from created resources maps (inches)
- $A_c$  = factor converting for resource map cell size to acres
- $T_c$  = constant, 150 short tons per acre-inch estimate for bituminous coal (Wood and others, 1983)

## RESULTS

Maps depicting the base elevation structure and original, mined-out, remaining, restricted, and available coal resources were created for the Pittsburgh coal bed in Ohio. These maps were used to calculate statewide and county coal resource estimates and the results are shown in plates at the end of the report or as insets in the plates. Table 2 shows the total coal resources, summarized by county with state totals, for the Pittsburgh coal bed. Values represented in the text and depicted in the plates represent the median value of the estimations. The appendix contains charts and tables of the distribution values of the resource estimations summarized by county.

### Structure Map

Plate 1 shows the extent and base elevation structure for the Pittsburgh coal bed in Ohio. A total of 47,714 elevation data points were used to construct this map. Data points are clustered in the northern portion of the study area, where the highest concentration of mines are located, and in the western portions close to the outcrop of the coal bed. Data points also are clustered in Gallia and Lawrence Counties where supplemental outcrop data were added to the dataset. Data points are sparsely distributed in the central region of the study area and in regions where the overburden is thickest near the Ohio River.

The Pittsburgh coal bed in Ohio underlies fourteen counties. Elevation of the base of the Pittsburgh coal in Ohio is between 184 and 1,312 ft above m.s.l. Highest elevations are in Jefferson and Harrison Counties, and the lowest elevations are along the Ohio River in Monroe, Washington, and Athens Counties. The Pittsburgh coal bed dips approximately 20 ft per mi to the southeast.

### Original Resources

Original resources are defined as the amount of coal estimated to have been present prior to mining. Plate 2 shows the original resources for the Pittsburgh coal in Ohio. A total of 2,725 thickness data points were used to create this map. Data points are clustered in the northern portion of the study area, where the highest concentration of mines is located, and along outcrop areas in the western extent. Large portions of Washington, Meigs, and Gallia Counties are devoid of data.

Prior to mining, approximately 7.9 billion short tons of Pittsburgh coal existed in Ohio. Data points show that the thickness of the Pittsburgh coal bed varies from 0 to 177 in in Ohio. However, the maximum thickness data points were isolated and found near points showing considerably lower thickness values; thus the interpolation technique smoothed the data to a maximum thickness of 98 in. The thickest widespread deposits occur in Belmont and Monroe Counties. Belmont County contained 36 percent, 2.8 billion short tons, of the original resources of the Pittsburgh coal in Ohio.

### Remaining Resources

Remaining resources were determined by subtracting areas of coal resources that were removed by surface and underground mining from areas of original resources. Plate 3 depicts the remaining resources of the Pittsburgh coal bed in Ohio. Approximately 43 percent of the Pittsburgh coal bed has been mined in Ohio; approximately 4.5 billion short tons of the 7.9 billion tons of original resources remain.

Of the remaining resources, 3.9 billion short tons are deep-minable coal and 535 million short tons are surface-minable coal. Monroe County has the highest amount of remaining deep-minable Pittsburgh coal remaining with 1.3 billion short tons. Jefferson County has the highest amount of remaining surface-minable reserves with 78 million short tons.

### Available Resources

Areas containing available resources were constructed by subtracting the areas restricted by land-use and technological factors from areas containing remaining resources. Approximately 2.9 billion short tons of the Pittsburgh coal are available for deep and surface mining.

#### *Deep-minable coal*

Plate 4 shows the extent and thickness of the available deep-minable coal for the Pittsburgh coal bed in Ohio and the extents of the restrictions. After removing 1.3 billion short tons of coal because of restrictions from the 3.9 billion short tons of remaining deep resources, an estimated 2.6 billion short tons are avail-

TABLE 2. Median estimation of coal tonnages<sup>1</sup> for the Pittsburgh (No. 8) coal bed in Ohio, by county and type of availability

County	Surface-Minable				Deep-Minable							
	Original Resources	Remaining Resources	Mined Resources	Available Resources	Remaining Resources	Technologically Restricted Resources	Land-Use Restricted Resources	Available Resources				
Athens	396,185	371,760	24,425	30,188	43,996	13,807	13,807	30,188	327,764	191,731	5,910	130,123
Belmont	2,838,069	837,056	2,001,014	49,972	100,418	50,446	50,446	49,972	736,637	808	9,039	726,791
Carroll	9	2	7	-	-	-	-	-	2	-	-	2
Gallia	345,667	308,474	37,192	83,750	99,367	15,617	15,617	83,750	209,107	-	471	208,636
Guernsey	78,144	40,982	37,163	11,007	14,837	3,830	3,830	11,007	26,145	11,293	190	14,662
Harrison	527,463	98,916	428,547	35,757	59,110	23,353	23,353	35,757	39,806	-	501	39,304
Jefferson	771,361	208,941	562,420	78,268	129,655	51,387	51,387	78,268	79,287	-	2,137	77,150
Lawrence	64,643	52,829	11,814	13,653	15,875	2,222	2,222	13,653	36,955	23	6	36,926
Meigs	187,909	182,122	5,787	19,603	31,587	11,984	11,984	19,603	150,535	63,909	3,278	83,348
Monroe	1,551,702	1,341,782	209,920	173	782	609	609	173	1,341,000	137,379	49,706	1,153,914
Morgan	250,966	225,422	25,544	14,408	19,032	4,624	4,624	14,408	206,390	166,468	3,993	35,929
Muskingum	70,586	30,939	39,647	3,029	3,713	684	684	3,029	27,226	27,226	-	-
Noble	262,378	233,833	28,545	3,353	5,007	1,654	1,654	3,353	228,826	212,153	371	16,302
Washington	529,580	527,130	2,451	4,834	11,669	6,835	6,835	4,834	515,460	451,045	4,072	60,343
<b>OHIO TOTAL<sup>2</sup></b>	<b>7,874,662</b>	<b>4,460,186</b>	<b>3,414,476</b>	<b>347,993</b>	<b>535,047</b>	<b>187,053</b>	<b>187,053</b>	<b>347,993</b>	<b>3,925,140</b>	<b>1,262,034</b>	<b>79,675</b>	<b>2,583,431</b>

<sup>1</sup>Thousands of short tons.

<sup>2</sup>Any tally inconsistencies are due to rounding of tonnages to the nearest ton.

able for deep mining. Monroe County has the highest amount of available resources with 1.2 billion short tons of deep-minable reserves.

### *Surface-minable coal*

Plate 5 shows the extent and thickness of the available surface-minable coal for the Pittsburgh coal bed in Ohio and the extents of the restrictions. After removing 187 million tons of coal because of restrictions from the 535 million tons of remaining surface resources, an estimated 348 million short tons are available for surface mining. Gallia County has the highest amount of available resources with 84 million short tons of surface-minable reserves.

## **DISCUSSION**

### **Uncertainty in the Methodology**

Every effort was made to ensure that the methods used in the study resulted in an accurate estimation of the coal resources. However, deviations in the methodology from the previous studies potentially could have impacted the accuracy of the results.

Some outliers and miscorrelated points possibly were not removed from the dataset. This introduces some uncertainty into the estimate especially in areas of low data density where correlations are difficult to make.

The study area of this report encompasses a much larger area than most previous studies. This estimation covered 3,000 mi<sup>2</sup>, while Olea and Luppens (2014) covered only an estimated 400 mi<sup>2</sup>. Thus the methodology had to be adapted to deal with some of the issues that appear in such a large dataset, such as ArcGIS reaching its processing limitations at a cell size of 500 ft<sup>2</sup>.

For this study, ArcGIS software was used to perform the estimations, whereas Olea and Luppens (2014) used the Stanford Geostatistical Modeling Software, a more robust statistical package. The advantages of ArcGIS include allowing for quickly calculating and removing restricted coal resources. However, ArcGIS had limitations in the processing capability for a large study area and lacked some interpolation techniques. For example, ArcGIS can perform sequential Gaussian simulation, though it cannot perform sequential indicator simulation. Therefore, one indicator kriging realization was used to remove data where coal had only a 15 percent probability, or less, of being present. Using only one realization instead of 100 realizations, as described by Olea and others (2011), should not have much effect on the estimation because all coal below 14 in is removed in subsequent processes. Thus even if the multiple realizations would more accurately model areas of coal presence or absence, most of

these areas of low coal thickness would be removed from the estimate anyway.

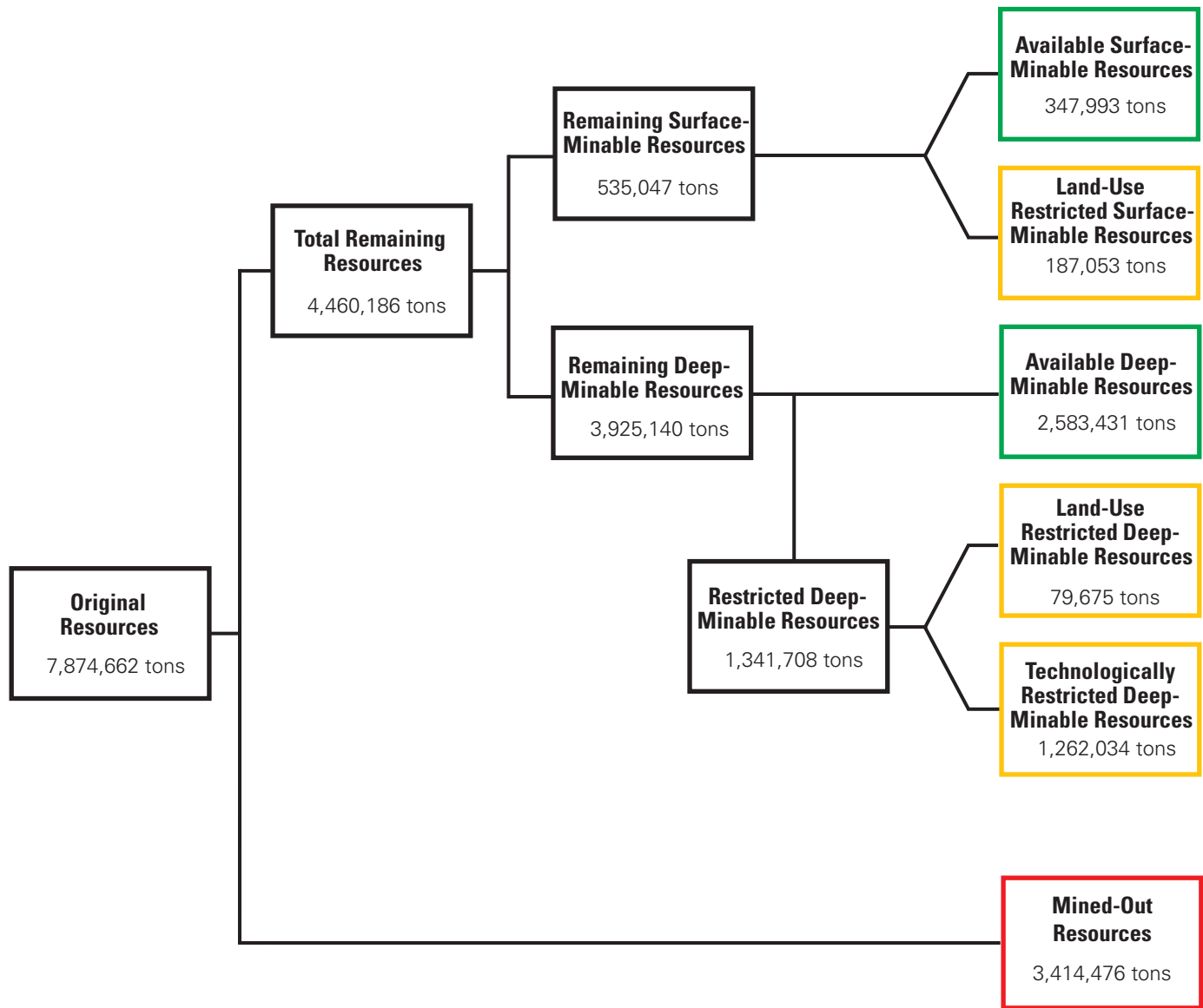
Because of the size of the study area, the methods diverged from Olea and Luppens (2014), and all coal farther than 3 mi from a data point was removed. This corresponds to the area of hypothetical resources as described by Wood and others (1984). Several regions in the study area have few data points, and some of these data points show large thicknesses of coal. Removing any coal beyond the 3-mi radius of a data point prevents the estimation from including large areas of coal where data are lacking, although this process may remove resource areas that potentially are present in the real world. Removing areas beyond 3 mi is important because of the increased likelihood of miscorrelation in low data density areas. The 3-mi boundary limits the impact of mistakes in the dataset and the interpolation in areas of no data.

### **Results**

The original resources tonnage estimate from this study, 7.9 billion short tons, surpasses previous estimates for Ohio. Tewalt and others (2001) estimated 5.9 billion short tons; Brant and DeLong (1960) estimated original reserves of 5.5 billion short tons; and Bownocker and Dean (1929) estimated less than 4.1 billion short tons. The higher estimate from this study is a result of the additional data in areas where no Pittsburgh data previously existed. In areas of low data density, each data point with minable thicknesses of coal significantly increases the tonnage for that county. The most significant differences in tonnages are in Washington and Meigs Counties, where the study by Tewalt and others (2001) had almost no data. In areas such as Belmont County, where large amounts of data were present for this and the previous study, tonnage calculations only vary by two percent.

Total estimate of coal mined from Ohio is 3.4 billion short tons. Thirty-seven percent of the original Pittsburgh coal bed is available to be mined today, amounting to 2.9 billion short tons.

In the Pittsburgh coal bed, there are 3.9 billion short tons of remaining deep-minable resources while there are only 535 million short tons of remaining surface-minable resources. In the future, land-use restrictions that impact the availability of surface mining could possibly increase because of urbanization and environmental regulations. However, technological restrictions could decrease the restrictions on deep-minable coal. Technological restrictions do not allow deep mining of coal thinner than 28 inches. Thirty-two percent (1.3 billion short tons) of the deep-minable Pittsburgh coal is less than 28 in thick. Future technologies may allow for deep mining of thin coal beds. Given that considerably more deep-minable coal remains



**FIGURE 10.** Summary of the median estimation of the coal resources (in thousands of short tons) in the Pittsburgh (No. 8) coal bed in Ohio.

than surface-minable coal, improvement in technology will allow for the Pittsburgh coal bed to become an even more economically important resource for Ohio.

Historically, the Pittsburgh coal bed has been the highest producer of all Ohio coals (Wolfe and Stucker, 2014). This trend stands to continue for the foreseeable future as there are 2.9 billion short tons (37 percent) of its original tonnage available for mining. Results for the Pittsburgh (No. 8) coal are summarized in Figure 10.

## CONCLUSIONS

Evaluation of the Pittsburgh (No. 8) coal bed in Ohio—the first statewide estimation of coal resources of that unit in 14 years—reveals that the Pittsburgh coal bed has 2.9 billion short tons of available resources.

This study estimates that approximately 7.9 billion short tons of Pittsburgh coal existed in Ohio before

mining. Of that amount, 3.4 billion tons have been mined and approximately 4.5 billion tons remain. Of the remaining resources, 348 million short tons are available to be mined through surface mining, and 2.6 billion short tons are available to be mined through underground methods. The majority of the remaining reserves exist in Belmont and Monroe Counties. At the current rate of mining for the Pittsburgh coal bed, these resources will last for more than a century.

## ACKNOWLEDGMENTS

The research on which this report is based was funded by the Ohio Coal Development Office. The author thanks the ODNR Division of Mineral Resources Management for access to its records and William Siplivy for his work in reviewing this report.

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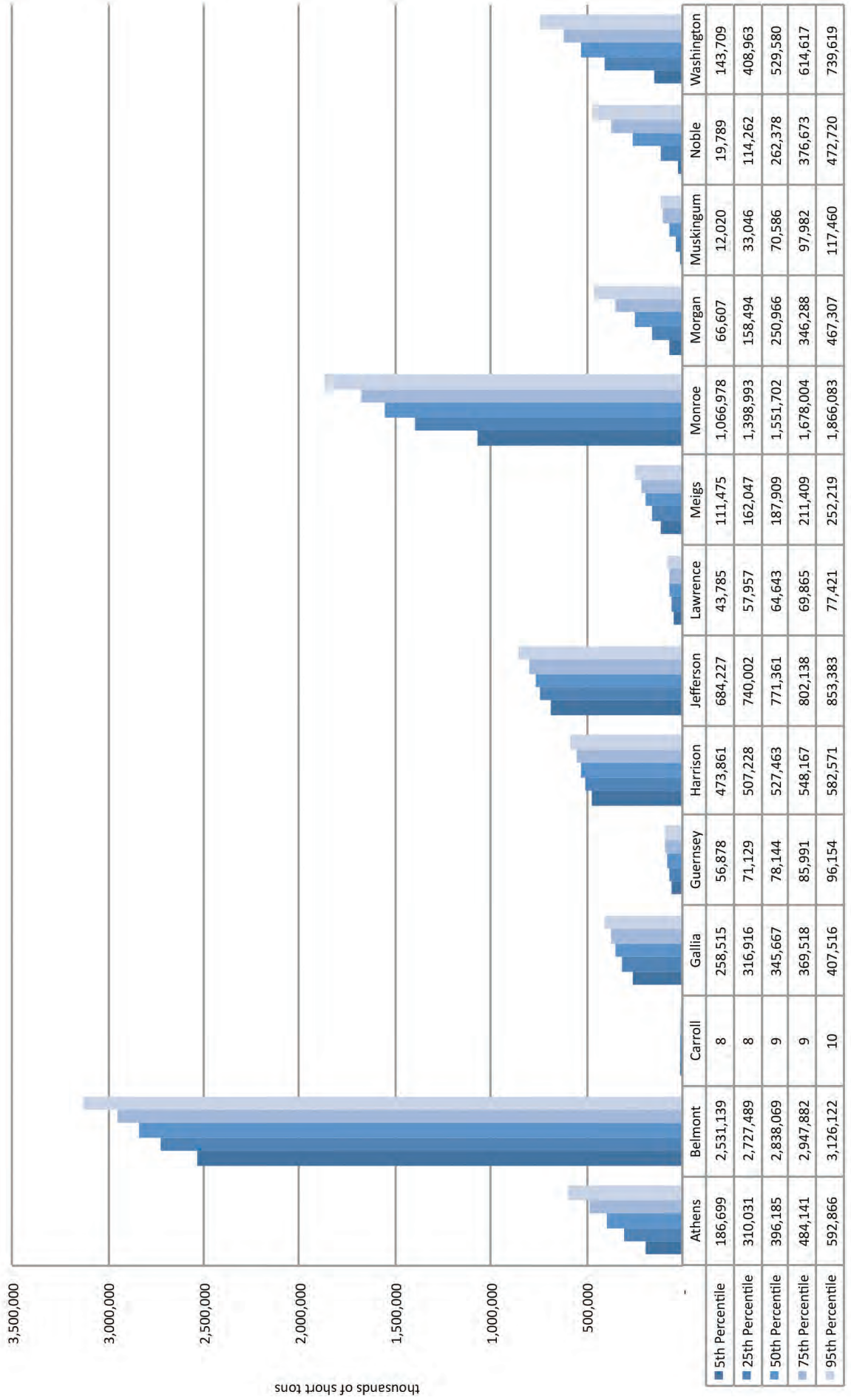


Figure A1. Percentile estimations of original resources for the Pittsburgh (No. 8) coal bed in Ohio, by county. Quantities in thousands of short tons.

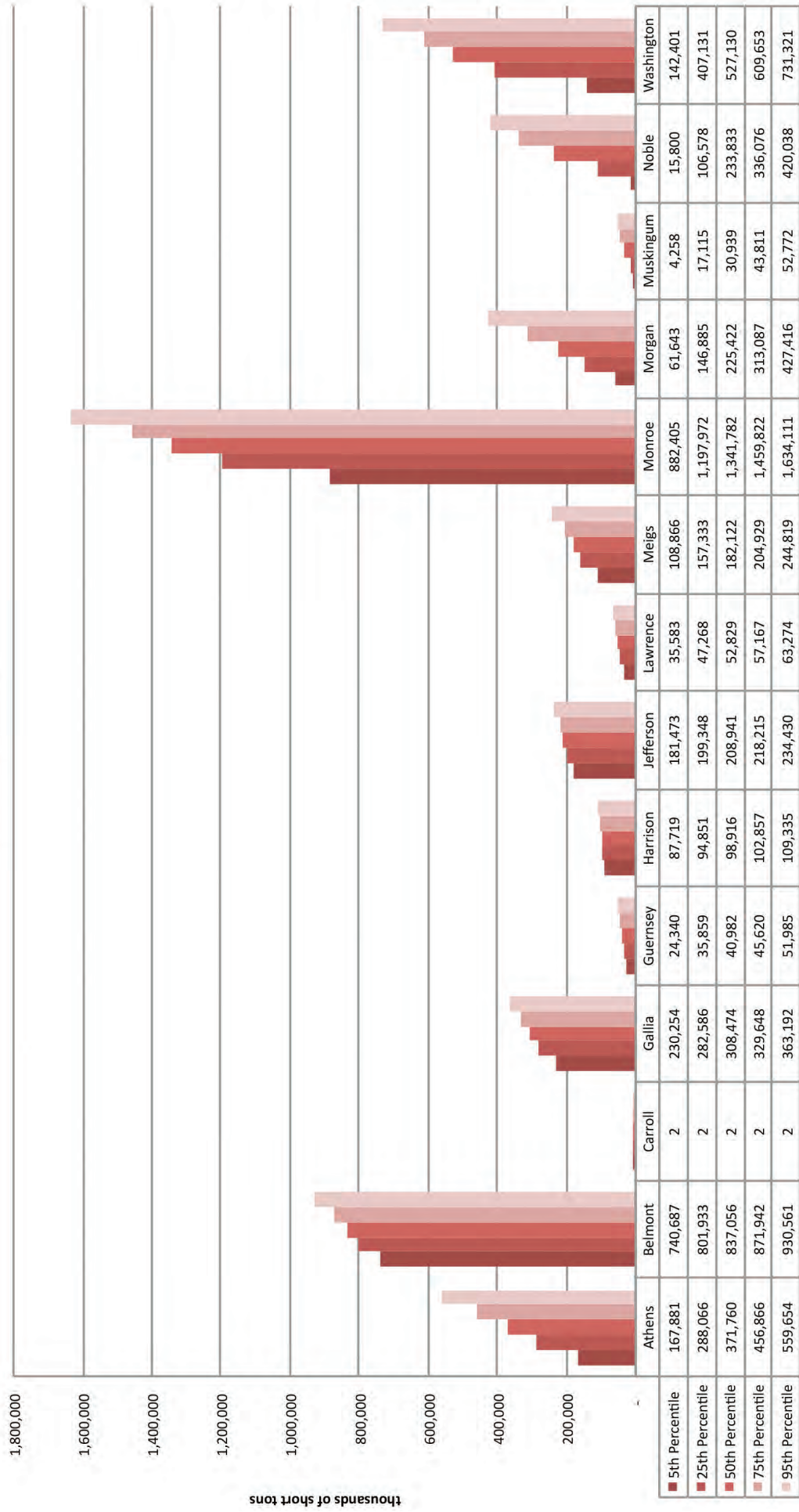


Figure A2. Percentile estimations of remaining resources for the Pittsburgh (No. 8) coal bed in Ohio, by county. Quantities in thousands of short tons.

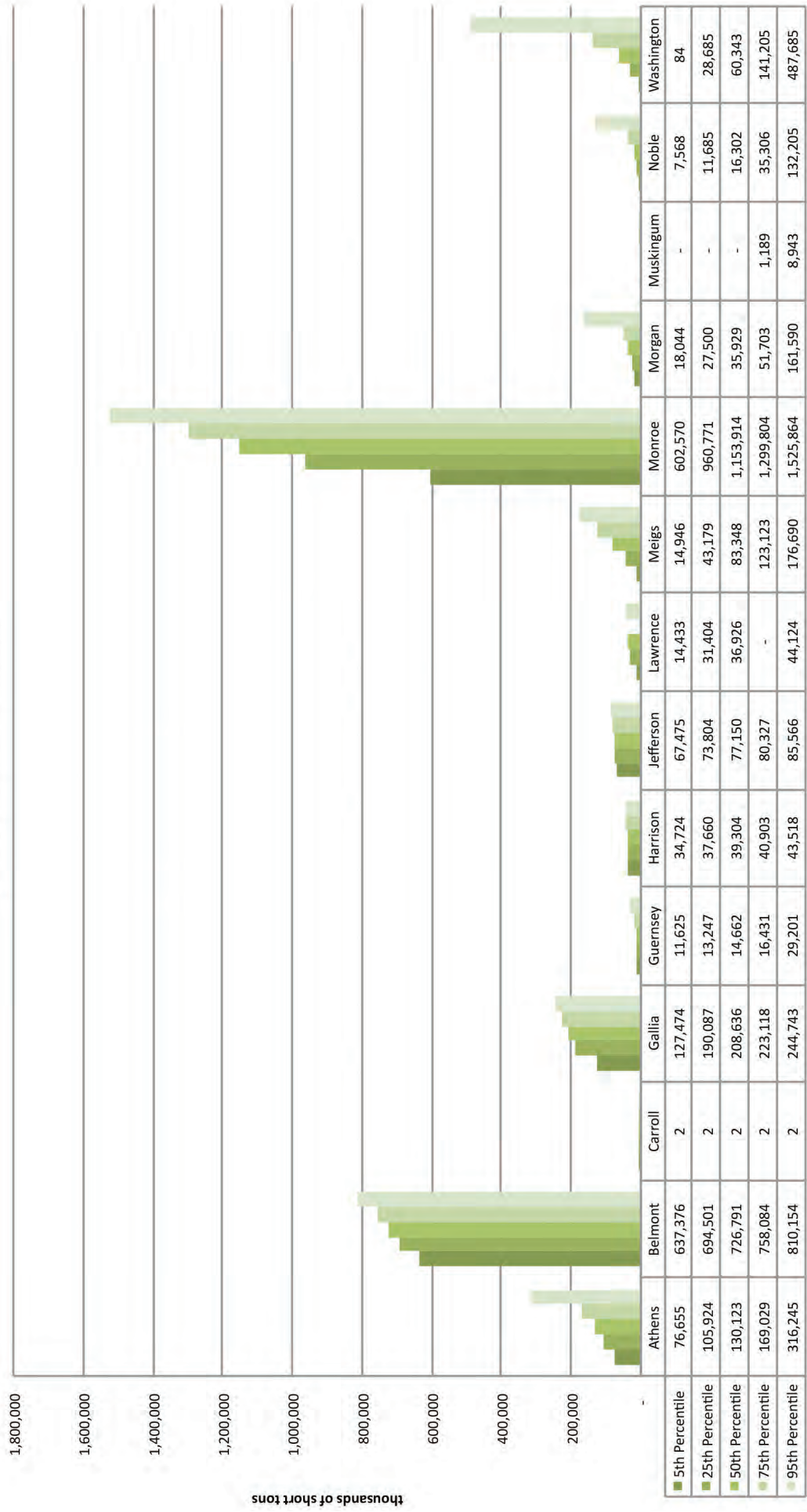


Figure A3 Percentile estimations of available deep-minable resources for the Pittsburgh (No. 8) coal bed in Ohio, by county. Quantities in thousands of short tons.

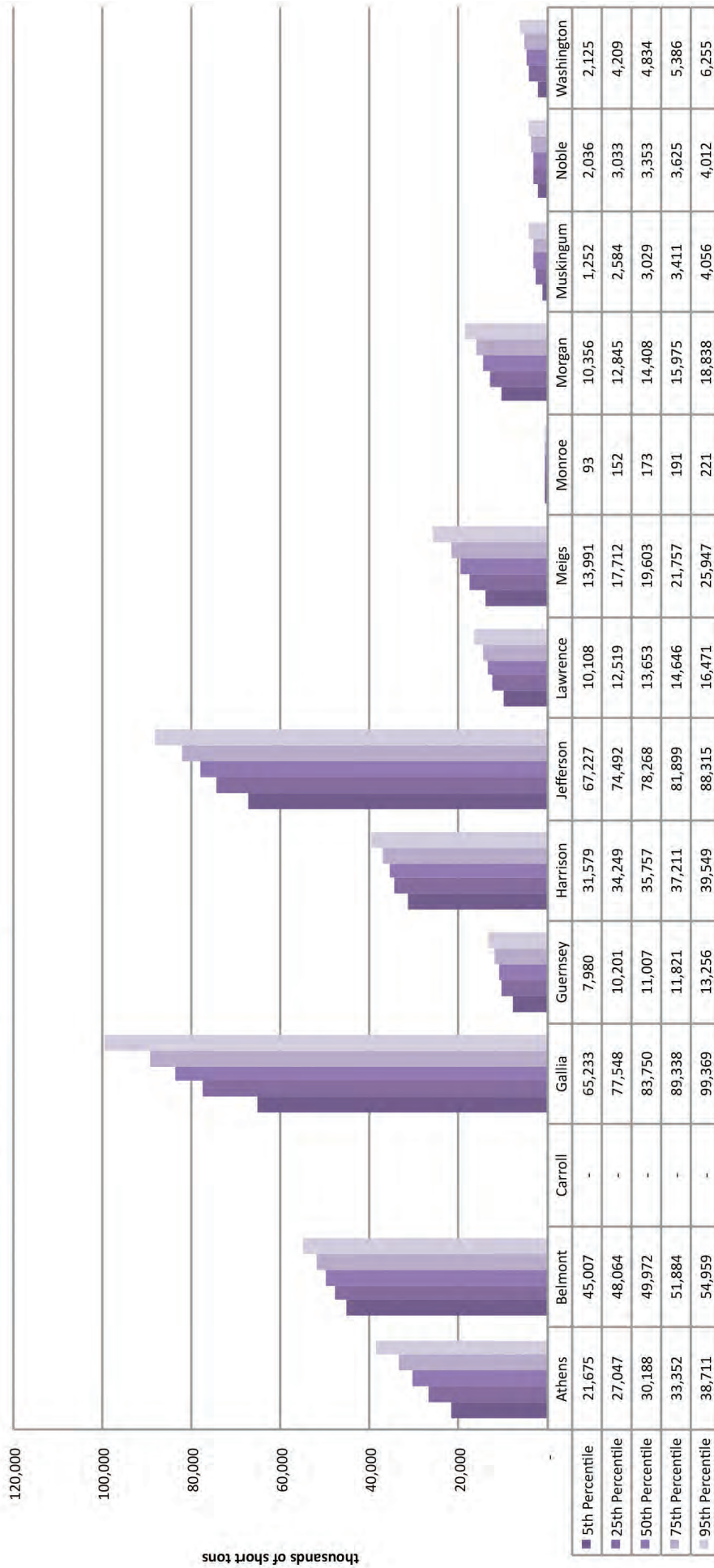


Figure A4. Percentile estimations of available surface-minable resources for the Pittsburgh (No. 8) coal bed in Ohio, by county. Quantities in thousands of short tons.



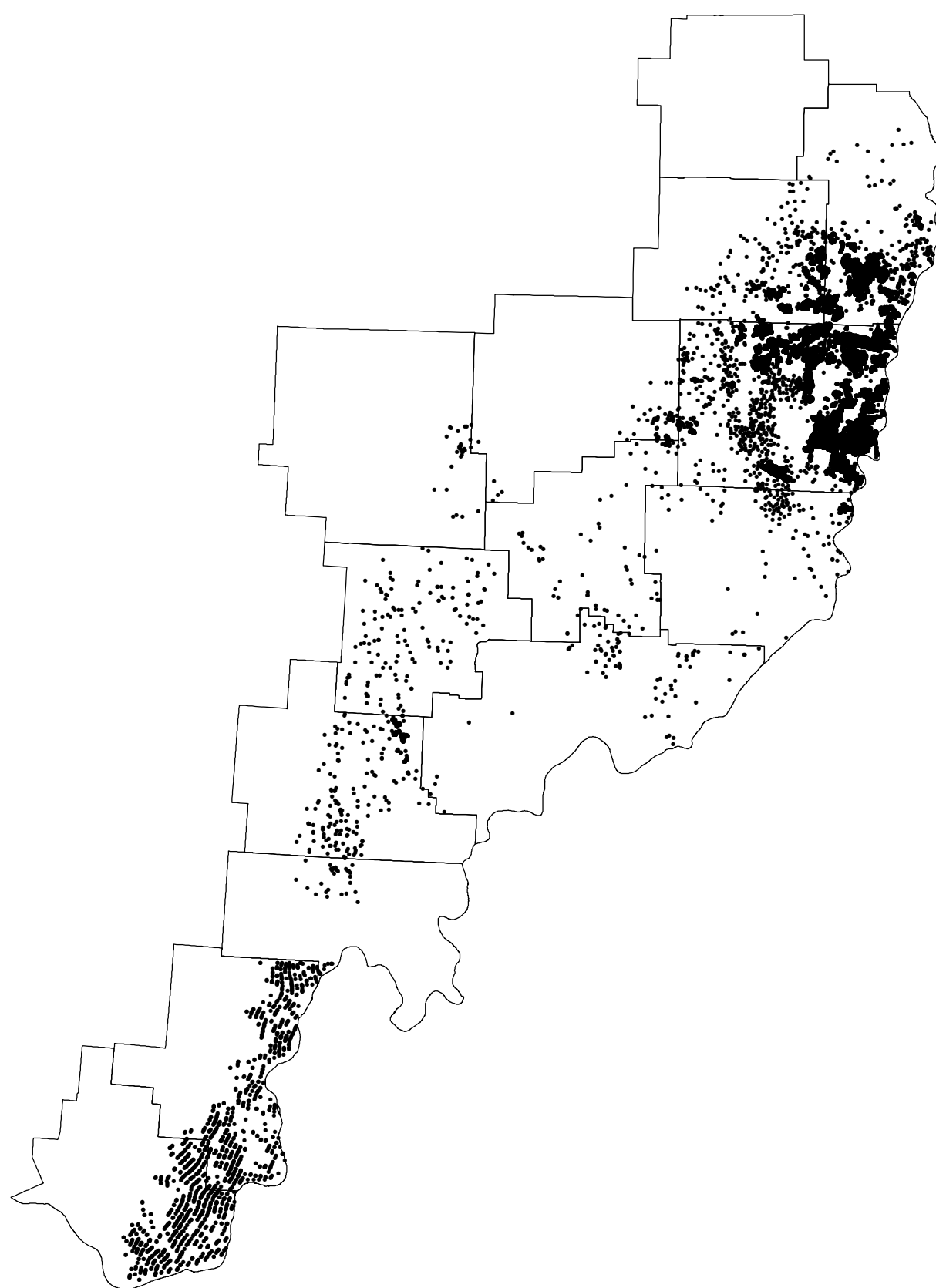
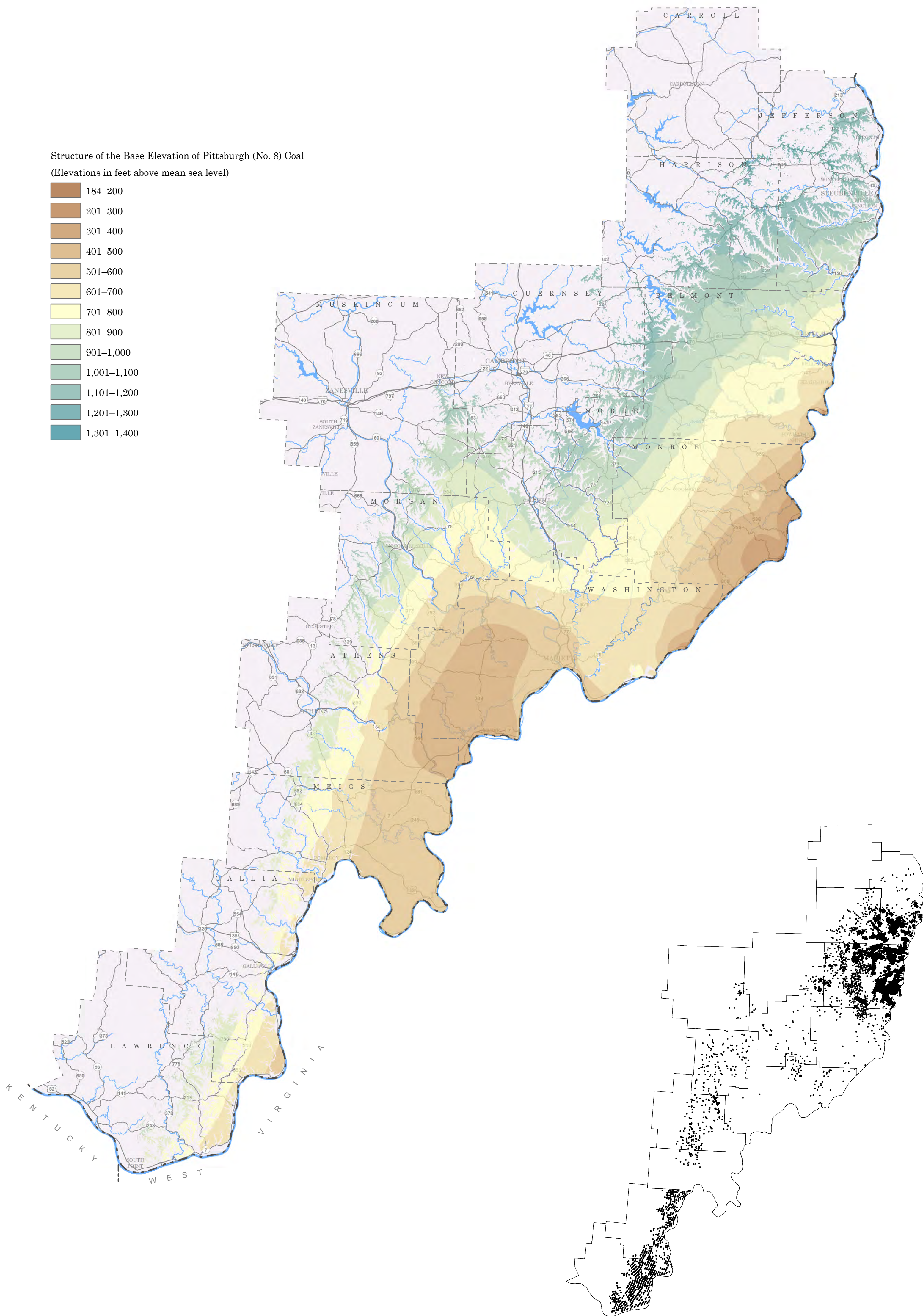
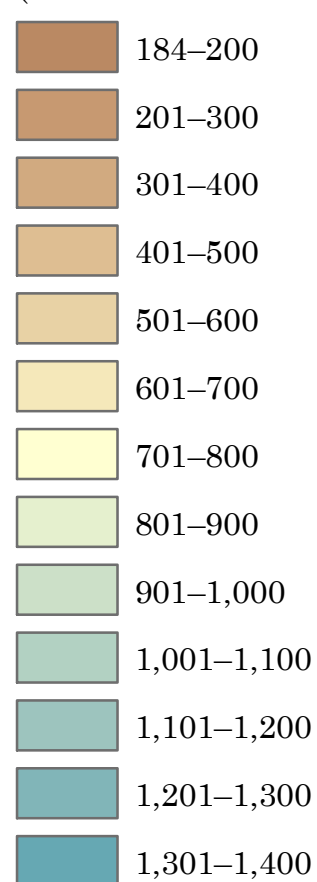


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by  
 Lee M. Sorrell and Paul N. Spahr

Structure of the Base Elevation of Pittsburgh (No. 8) Coal

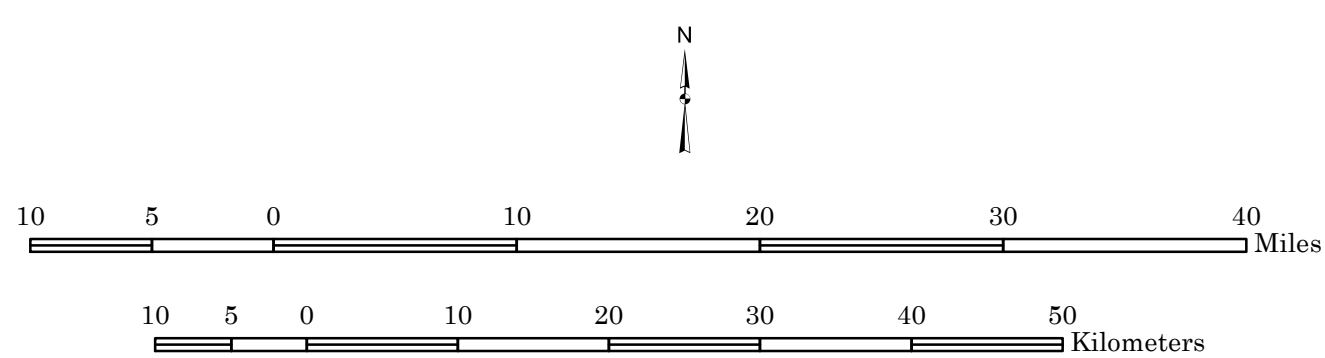
(Elevations in feet above mean sea level)



ELEVATION DATA POINTS



STUDY AREA



SCALE 1:500,000

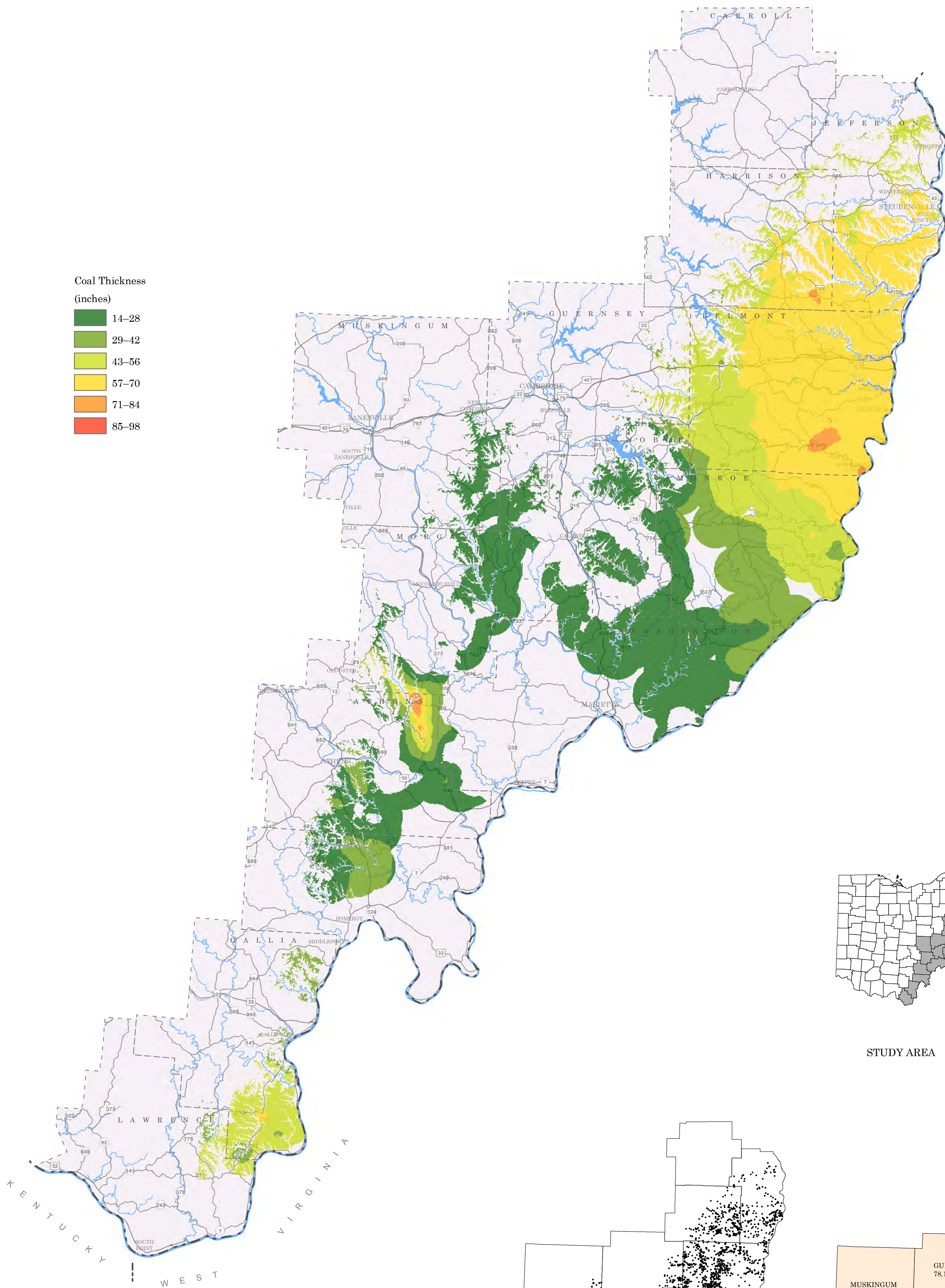
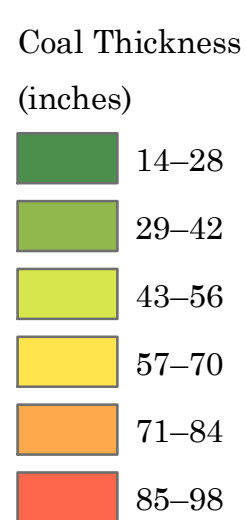
Projection is Ohio coordinate system,  
 south zone. North American Datum 1983.



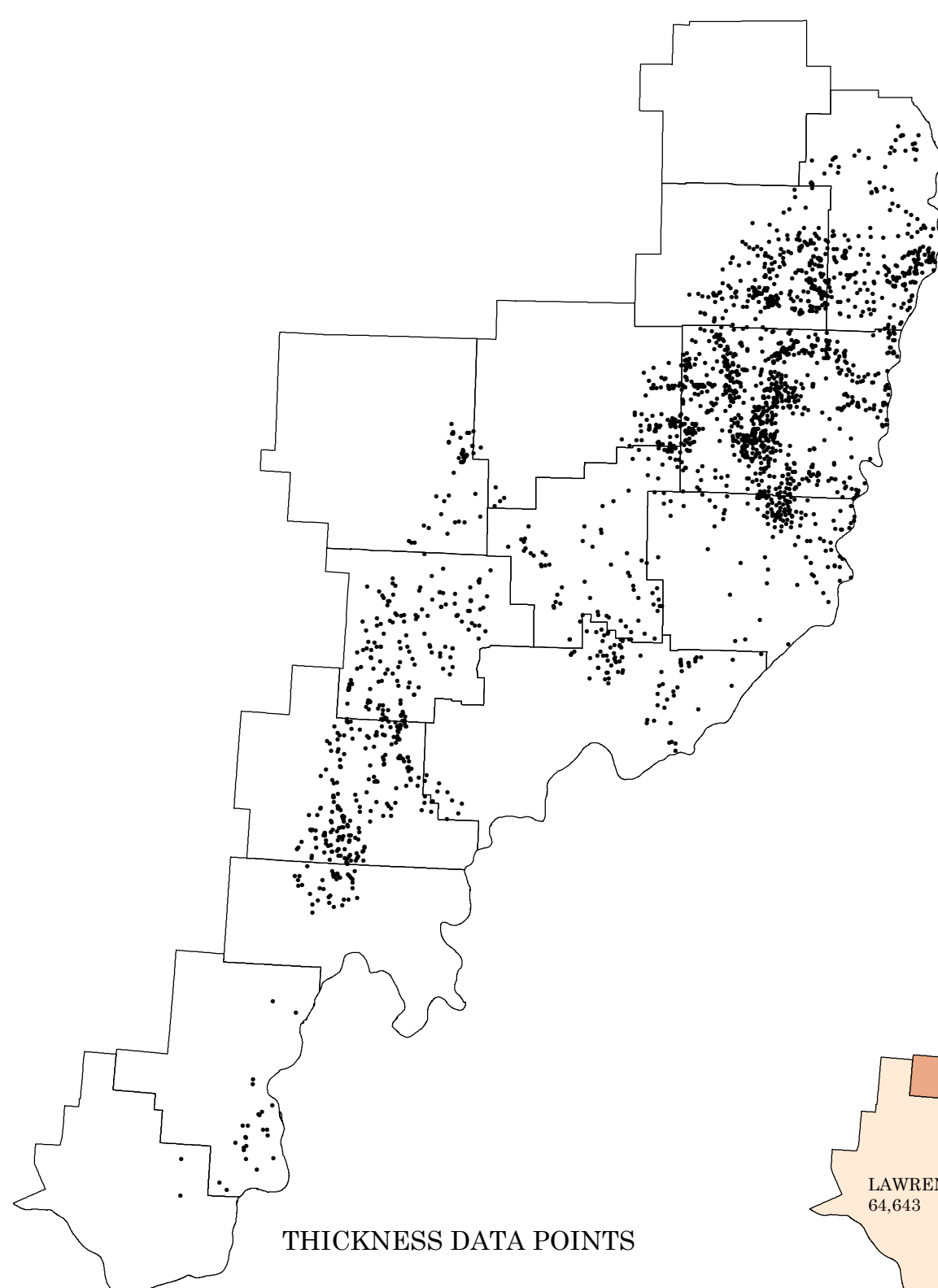
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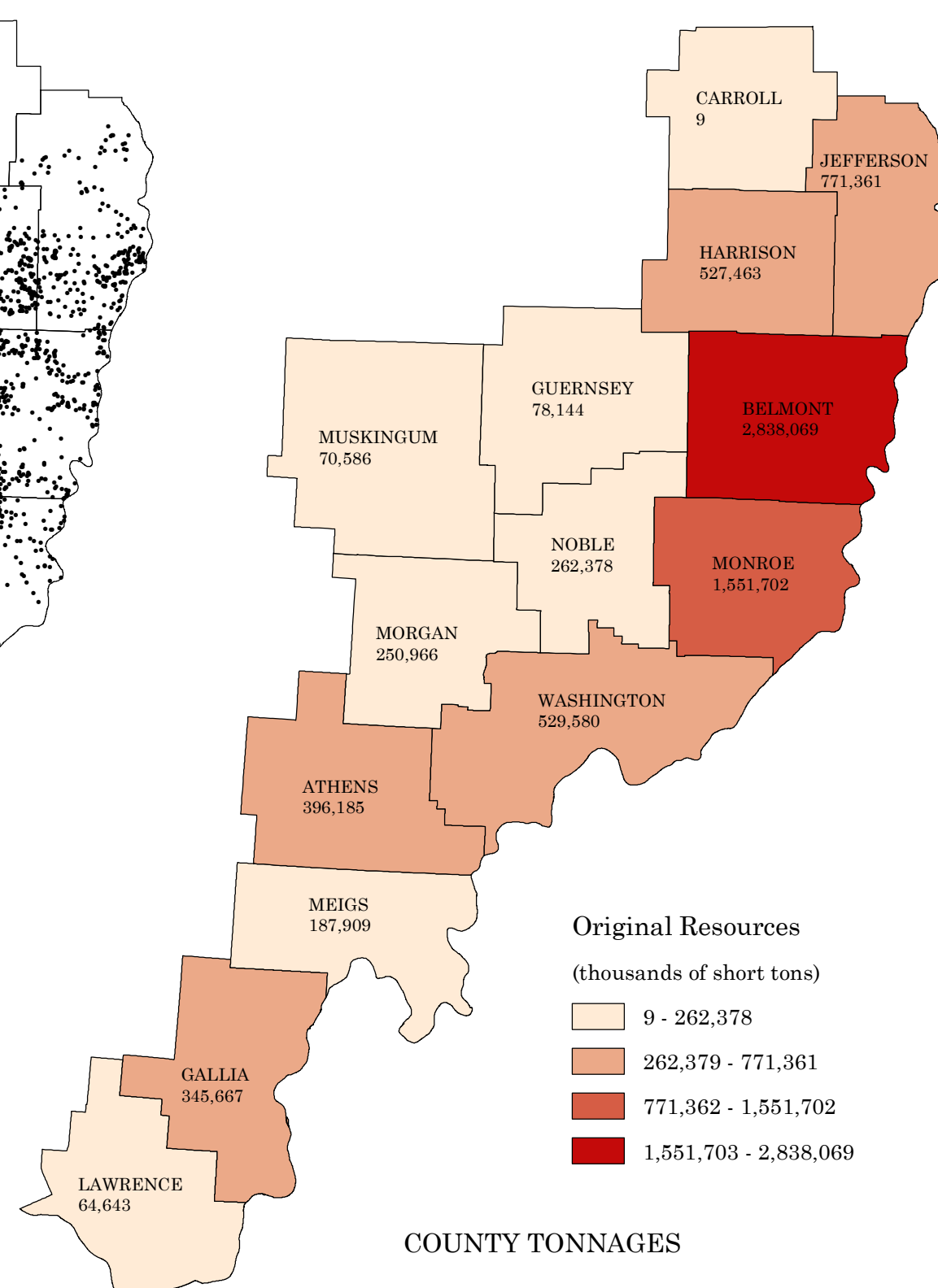
by  
Lee M. Sorrell and Paul N. Spahr



STUDY AREA



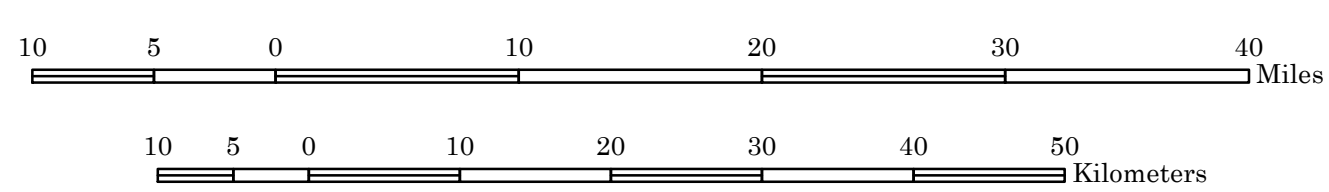
THICKNESS DATA POINTS



Original Resources  
(thousands of short tons)

- 9 - 262,378
- 262,379 - 771,361
- 771,362 - 1,551,702
- 1,551,703 - 2,838,069

COUNTY TONNAGES



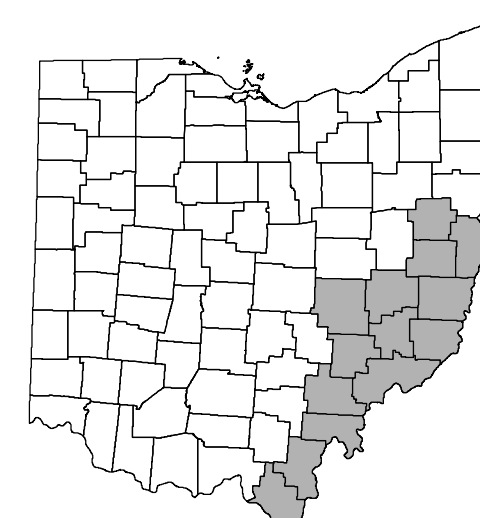
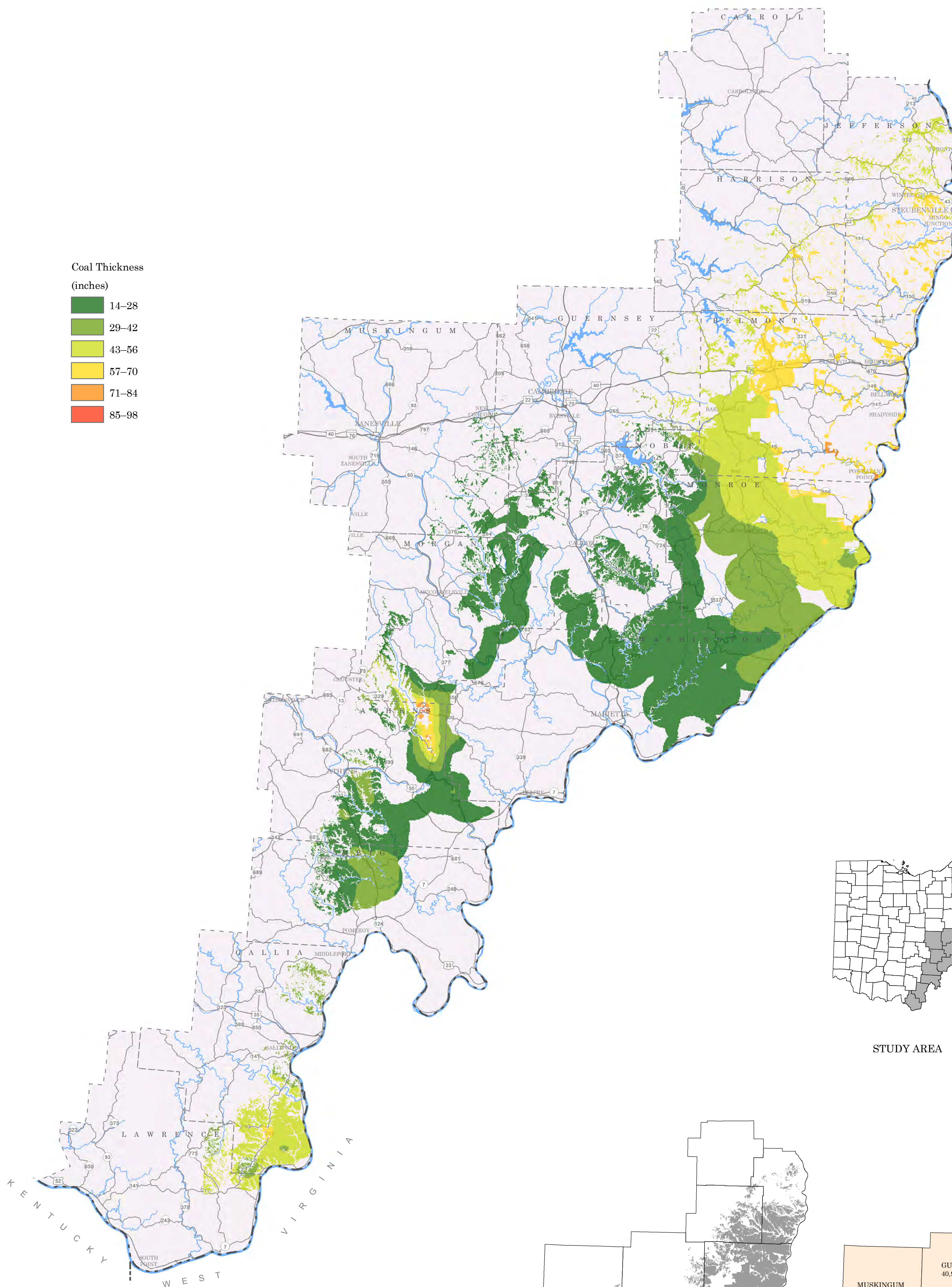
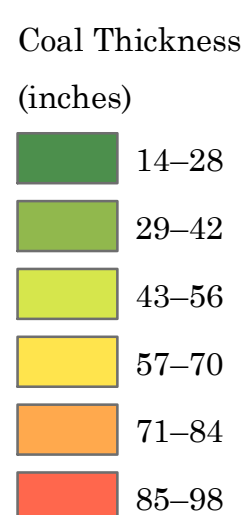
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Projection is Ohio coordinate system,  
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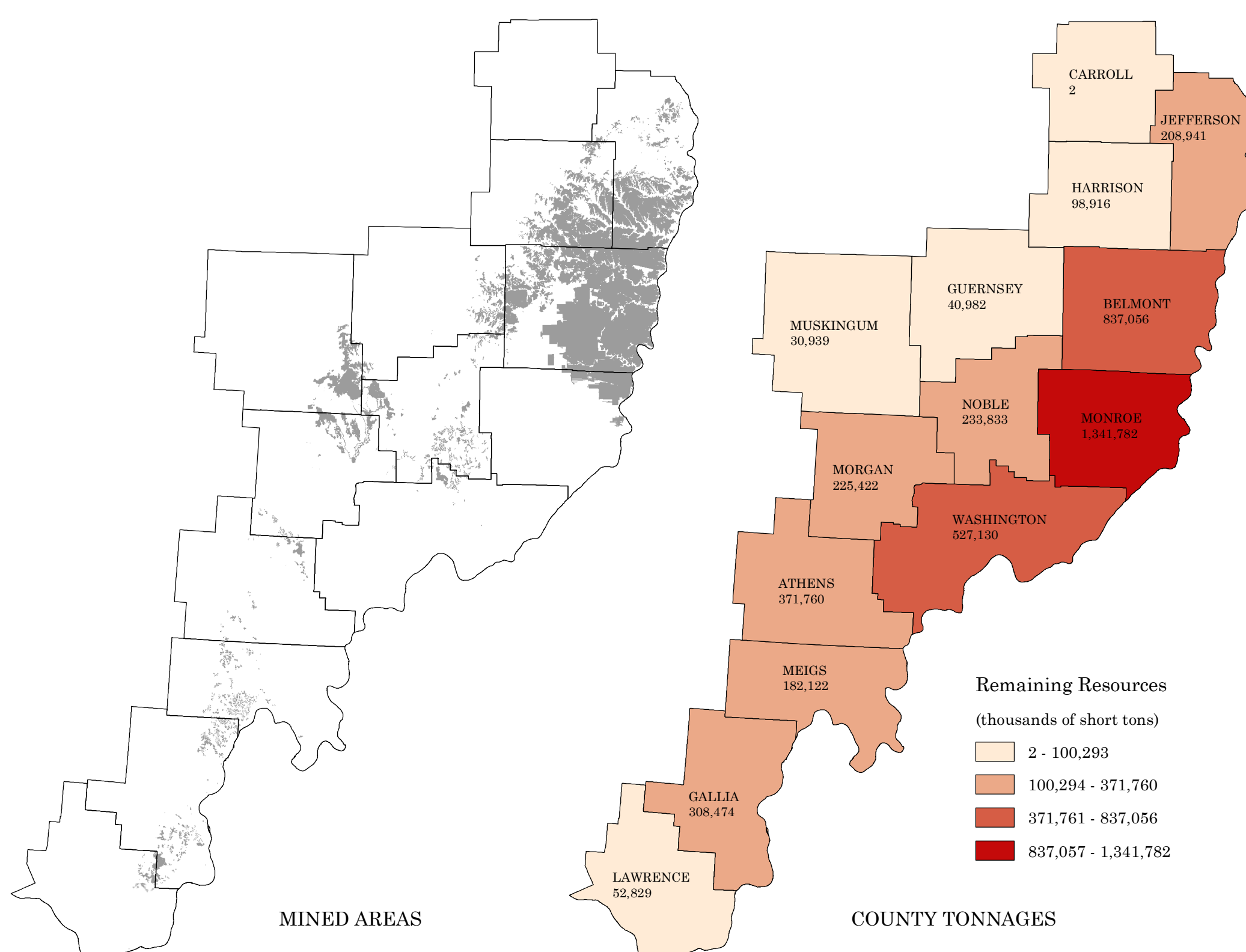
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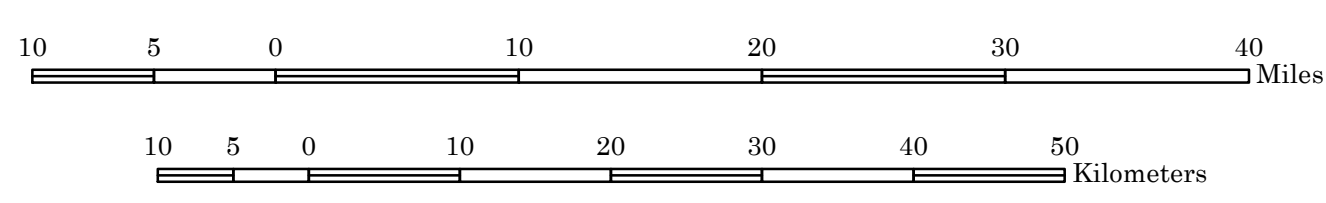


STUDY AREA



MINED AREAS

COUNTY TONNAGES



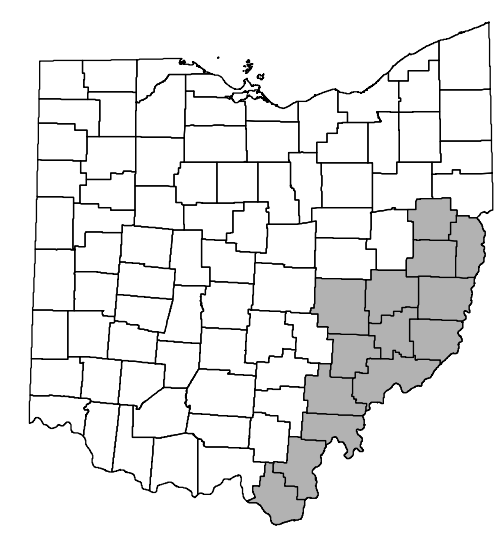
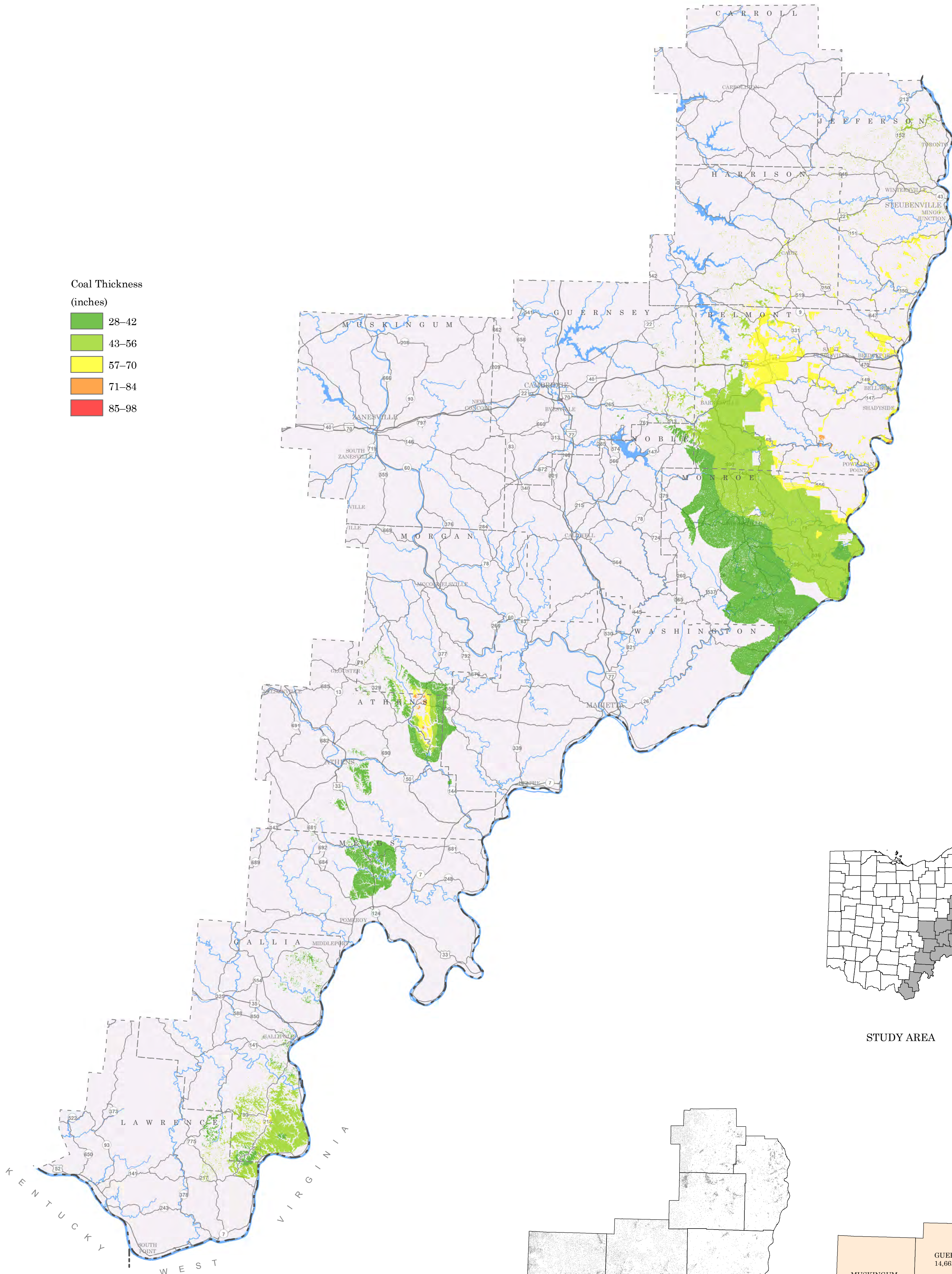
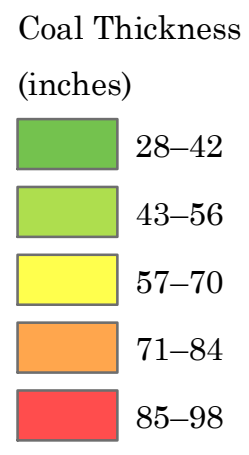
SCALE 1:500,000

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

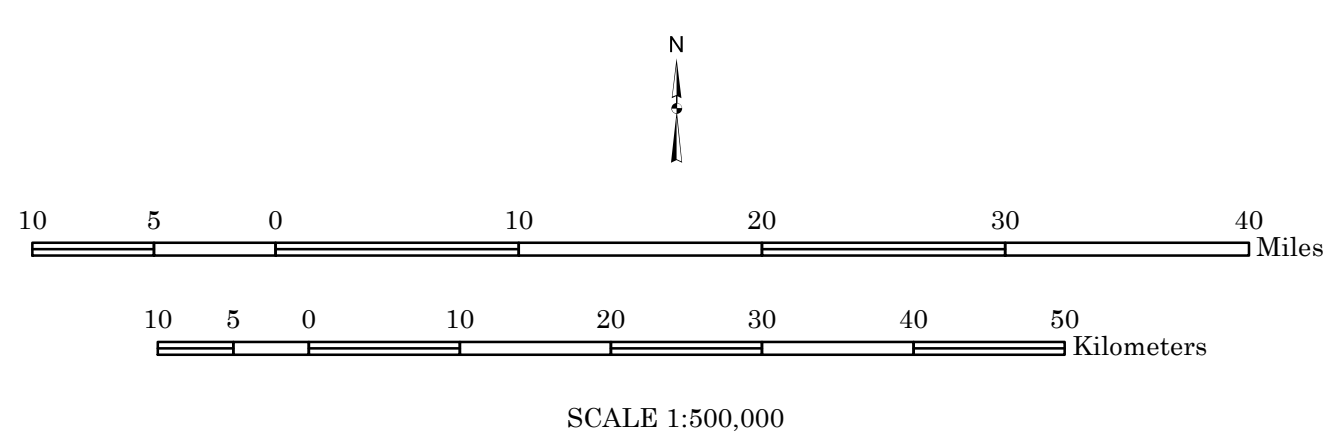
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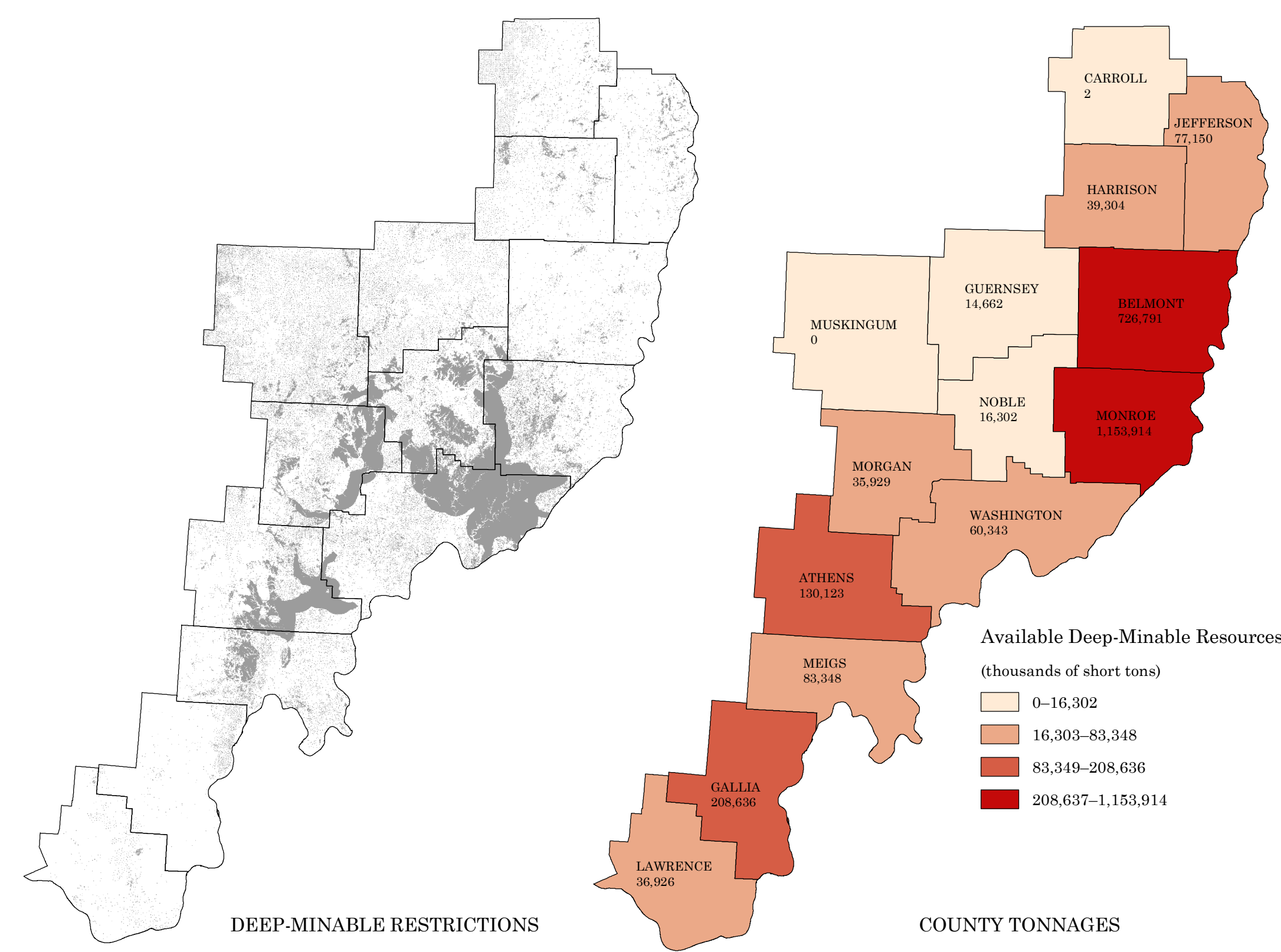
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STUDY AREA



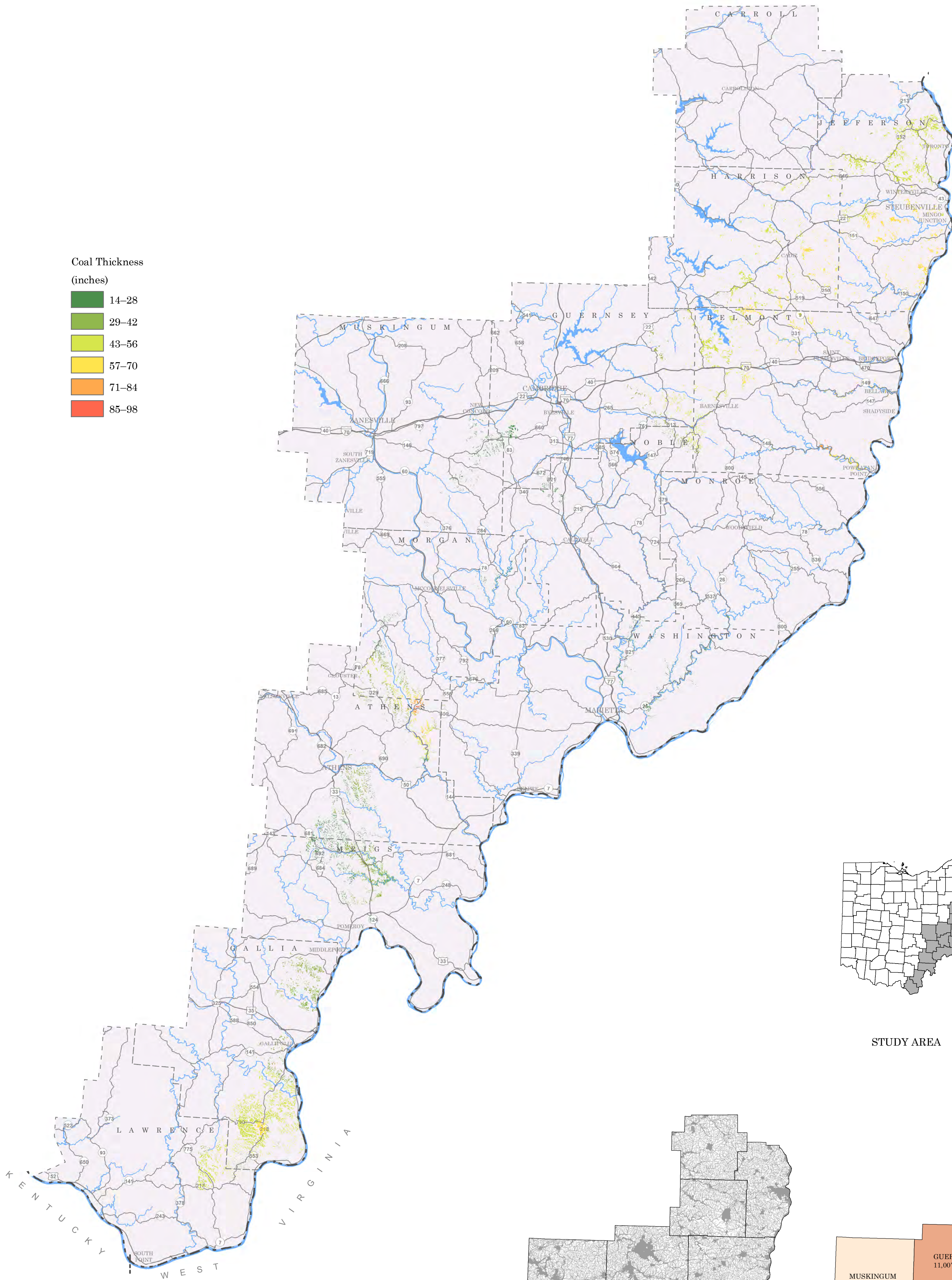
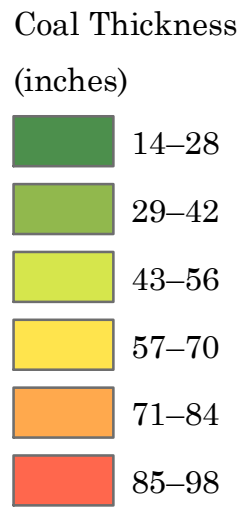
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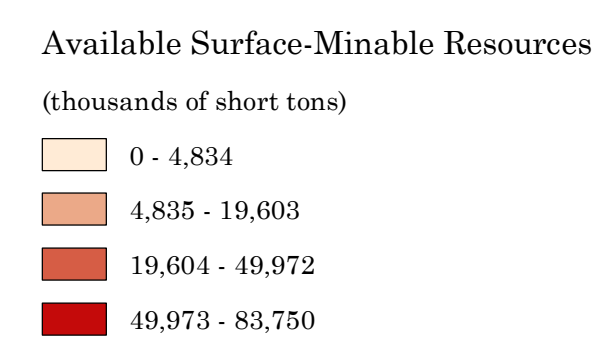
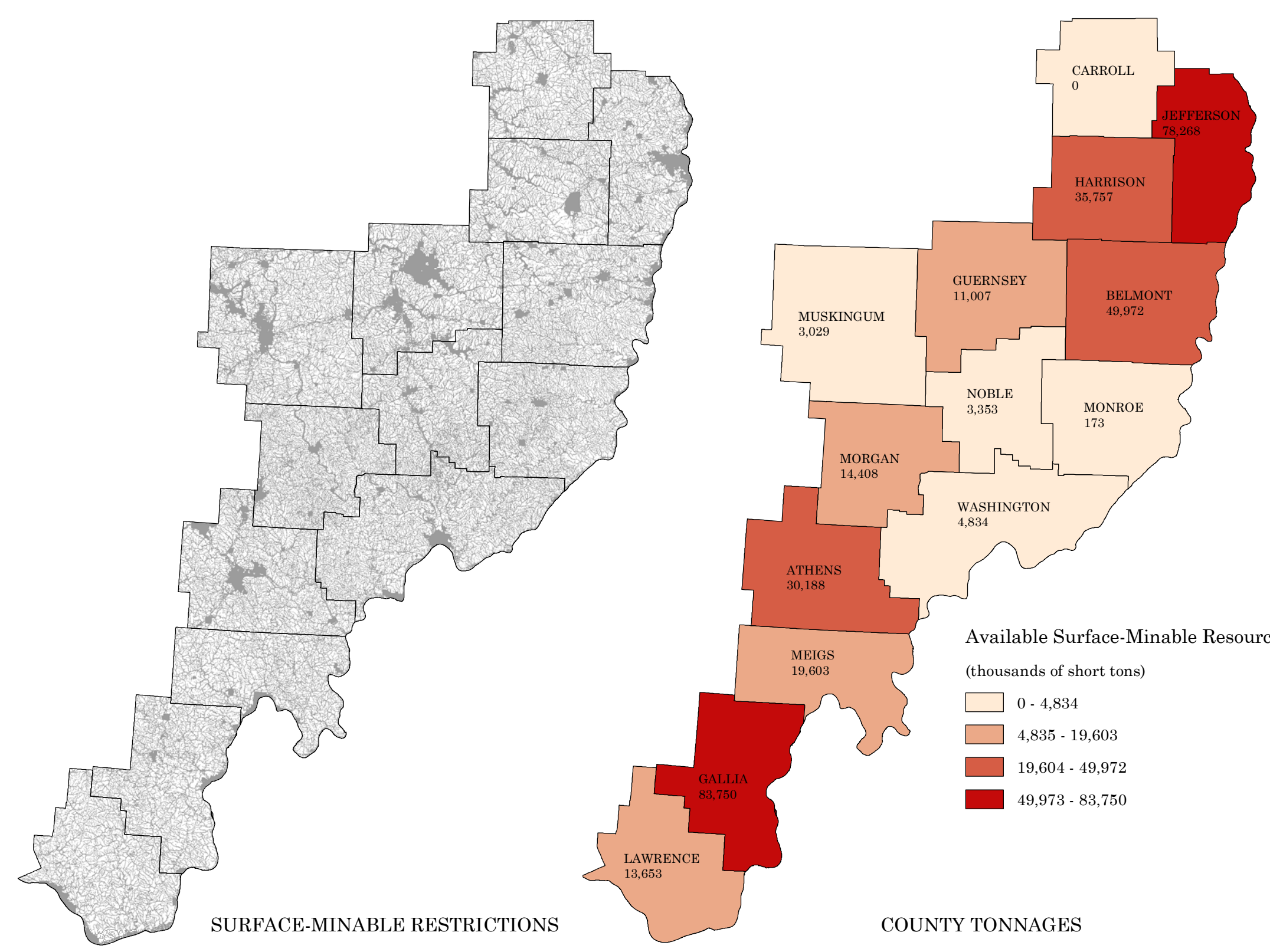
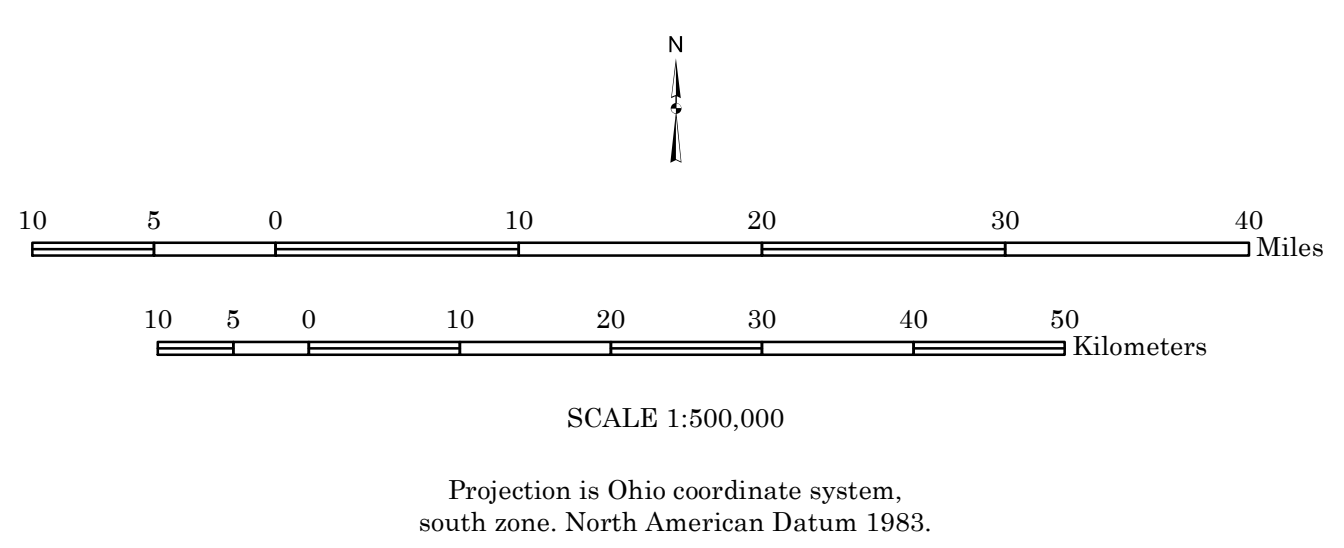
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STUDY AREA



SURFACE-MINABLE RESTRICTIONS

COUNTY TONNAGES

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