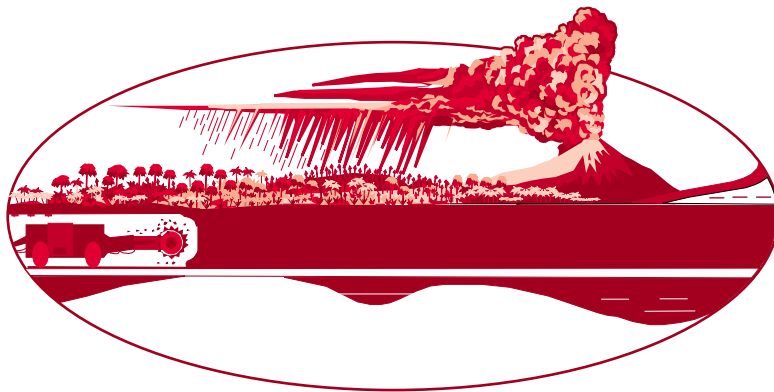


Kentucky Geological Survey
James C. Cobb, State Geologist and Director
University of Kentucky, Lexington

Available Resources of the *Fire Clay Coal* in Part of the Eastern Kentucky Coal Field



Stephen F. Greb,
Gerald A. Weisenfluh, Robert E. Andrews,
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One of the major goals of the Kentucky Geological Survey is to make the results of basic and applied research easily accessible to the public. This is accomplished through the publication of both technical and nontechnical reports and maps, as well as providing information through open-file reports and public databases.

Available Resources of the Fire Clay Coal in Part of the Eastern Kentucky Coal Field

Stephen F. Greb¹, Gerald A. Weisenfluh¹,
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James C. Cobb¹, and Richard E. Sergeant¹

ABSTRACT

Available resources for the Fire Clay coal were calculated for a 15-quadrangle area in the Eastern Kentucky Coal Field. Original coal resources were estimated to be 1.8 billion tons (BT). Coal mined or lost in mining was estimated at 449 million tons (MT), leaving 1.3 BT of remaining Fire Clay resources in the study area. Of the remaining resources, 400 MT is restricted from mining, primarily because the coal is less than 28 in. thick, normally considered too thin to mine underground using present technology. The total coal available for mining in the study area is 911 MT, or 52 percent of the original resource. Of the 911 MT, 14.9 percent is thicker than 42 in., and only 6.1 percent is accessible by surface-mining methods. The largest block of available coal is in the Leatherwood quadrangle, is less than 42 in. thick, and mostly occurs below drainage.

INTRODUCTION

Coal is Kentucky's most important energy resource. Previous estimates of eastern Kentucky's coal resources were approximately 64 billion tons (BT) of original coal resources greater than 14 in. thick (Brant, 1983a, b; Brant and others, 1983a-d). Records of coal production for eastern Kentucky from the Kentucky Department of Mines and Minerals indicate that from 1976 to 1992 more than 230 million tons (MT) of coal have been mined from the original resource.

Recent studies sponsored by the U.S. Geological Survey's (USGS) Coal Availability Program (for example, Eggleston and others, 1990) have shown that in many coal-mining areas not all of the remaining resources are available for mining. Coal availability is an approach to coal-resource estimation that considers land-use and technological restrictions that would prevent coal from being available for mining.

Coal-availability studies in nine 7.5-minute quadrangles in eastern Kentucky demonstrated that from 41 to 71 percent of the original coal is available for mining (for example, Andrews and others, 1994). Differences between the estimates of original resources and estimates of available resources are a function of the programs' different goals and the different methods used. The earlier program was designed to estimate the coal

resource in Kentucky greater than 14 in. thick. To determine this resource, the amount of coal produced was doubled and then subtracted from the total original resource. The amount of coal produced was doubled because in the most common form of underground mining, room-and-pillar mining, 50 percent of the coal is extracted and 50 percent is left in the ground as support pillars, which are not mined. Mining methods were not considered, or whether the coal might not be mineable because of restrictions.

In contrast, the Coal Availability Program measures the amount of coal restricted from mining because of technological and land-use reasons. Coal from 14 to 28 in. thick is considered surface-mineable only. Coal must be more than 28 in. thick to be considered available for deep mining. Also, coals that occur in areas restricted by local, State, or Federal regulations (such as near roads, towns, cemeteries, pipelines, etc.) are not included in estimates.

Because coal-availability studies examining all coals in a quadrangle have demonstrated that less coal may be available for mining than previously thought, it stood to reason that a study estimating the available resources of a single major coal in a multiple-quadrangle area might also find differences in the amount of coal available for mining than the original resource estimate indicated. To test this hypothesis, a regional availability

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study was conducted for the Fire Clay coal bed. This major resource is thick across a wide area, has a low sulfur content, is actively mined, and has a long history of production. Also, because of its market reputation, it is actively explored for.

In many ways, studying an economically important bed such as the Fire Clay coal across numerous quadrangles is as important as charting multiple coals in one area. In any individual quadrangle, a single restriction may be more significant than in other quadrangles, which could lead to biases when extrapolating results to larger areas. By looking at a single coal bed across multiple quadrangles, the likelihood of a unique restriction to mining occurring decreases. By examining a single coal across a wider area, we can account for a larger spectrum of mining conditions and geology than can be accounted for in a single quadrangle. Also, in any one area, coals that may be available for mining have never been mined. Many of these unmined coals are erratic in distribution and exhibit variable thickness or quality across short distances. Because they do not have a development history and are erratic, they require more elaborate mine planning and are less attractive for mining.

Fire Clay Coal Project

This is the last in a series of three publications concerning the Fire Clay coal. The first is a detailed analysis of the coal quality and trace elements in the Fire Clay coal in an eight-quadrangle area of the Eastern Kentucky Coal Field (Eble and others, 1999). The second publication (Greb and others, 1999) is a summary of the geology of the Fire Clay coal, and especially deals with coal-thickness and roof-geology trends in a 15-quadrangle study area that includes the 8-quadrangle study area of the first report. The current publication is a study of the available Fire Clay coal resources in the same 15-quadrangle study area as the second report. These three studies were coordinated in order to determine factors important to future coal development.

Regional Setting

The Fire Clay coal (also known as the Hazard No. 4 and Jackrock coals) is of Middle Pennsylvanian age (Fig. 1) and stratigraphically situated in the Hyden Formation of the Breathitt Group (previously known as the Breathitt Formation), midway between the top of the Kendrick and base of the Magoffin Members (Chesnut, 1992). It is one of the most heavily mined beds in eastern Kentucky; 22 MT of it was produced in 1993, or 18 percent of the coal mined in eastern Kentucky that year, according to records at the Kentucky Department of Mines and Minerals. The coal bed commonly occurs as

two benches separated by a flint-clay parting locally known as the “jackrock.” This parting makes the coal easy to identify and aids in regional correlation. The coal is high-volatile A bituminous, generally low in ash content (mean, 10 percent), and generally low in sulfur content (mean, 1 percent). Regional resource analysis of the coal shows that it is continuous across much of the coal field, but with variable thickness (Brant, 1983a, b; Brant and others, 1983a–d).

Study Area

The study area (Fig. 2) has a long history of mining, is still actively mined, and has numerous roadcut and abandoned highwall exposures in which the coal and surrounding strata can be observed. The area accounts for 30 percent of the original Fire Clay coal resource and 57 percent of the demonstrated Fire Clay coal resource (measured and indicated resources more than 28 in. thick), according to previous coal-resource studies (Brant, 1983a, b; Brant and others, 1983a–d). The area has also accounted for more than 40 percent of recent Fire Clay coal production, according to records at the Kentucky Department of Mines and Minerals. In general, the coal is thickest to the southeast toward Pine Mountain, and thins northwestward, occurring as a series of elongate regions of thick coal separated by areas of thin or absent coal (Fig. 3).

Purposes

The purposes of the Fire Clay coal-availability study were to (1) delineate areas where the Fire Clay coal is available for future mining in a region where it is still actively mined and of future economic importance, (2) quantify the thickness and mining characteristics of the coal in areas where it might be mined, and (3) compare

System	Series		Group	Formation	Lithology	Bed/Member
	Middle Pennsylvanian	Mid-Cont.				
Pennsylvanian	Middle	Atokan	Breathitt	Hyden		Magoffin Member
	Morrowan					Copland coal Hamlin coals Fire Clay rider coal Fire Clay coal (312 ± 1 Ma) Whitesburg coals Kendrick Member

Figure 1. Stratigraphic position of the Fire Clay coal.

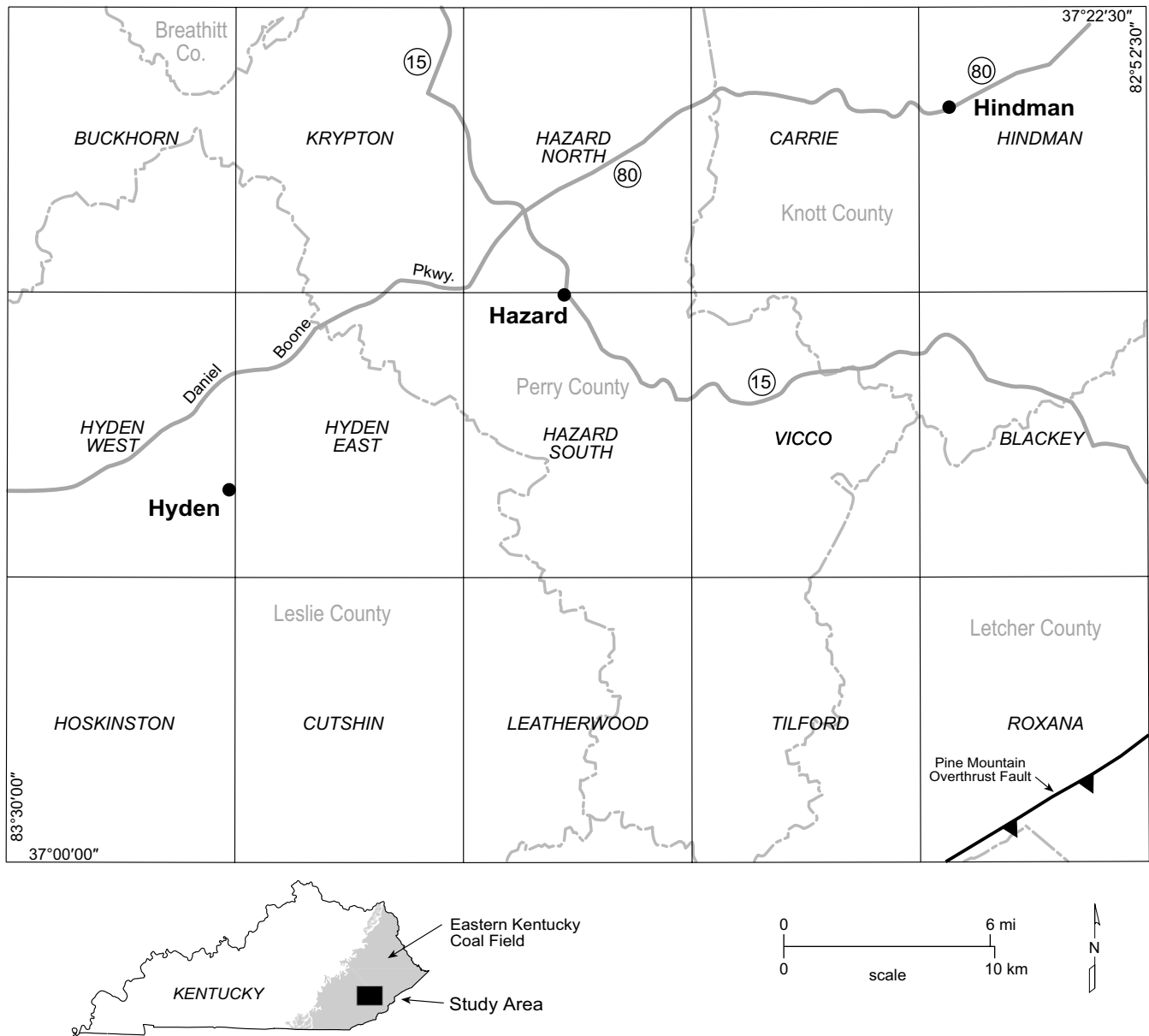


Figure 2. Location of the study area.

the availability of this single premium coal across multiple 7.5-minute quadrangles with the availability of multiple coals in a single 7.5-minute quadrangle.

METHODS

The methods for this study are similar to those used in previous quadrangle-scale availability studies (for example, Andrews and others, 1994). In order to calculate resources of a coal bed, the volume of coal in the area must be known. The area of the coal must be de-

finied by its outcrop limit, and the thickness of the coal must be estimated from point-source thickness data. Within this area, smaller volumes of coal that have been mined out or are in some way restricted from mining must be delineated. The most useful tool for measuring and calculating different volumes in an area is a computerized geographic information system (GIS). A GIS stores digital map data that can be used to make automated comparisons and calculations on one or more maps.

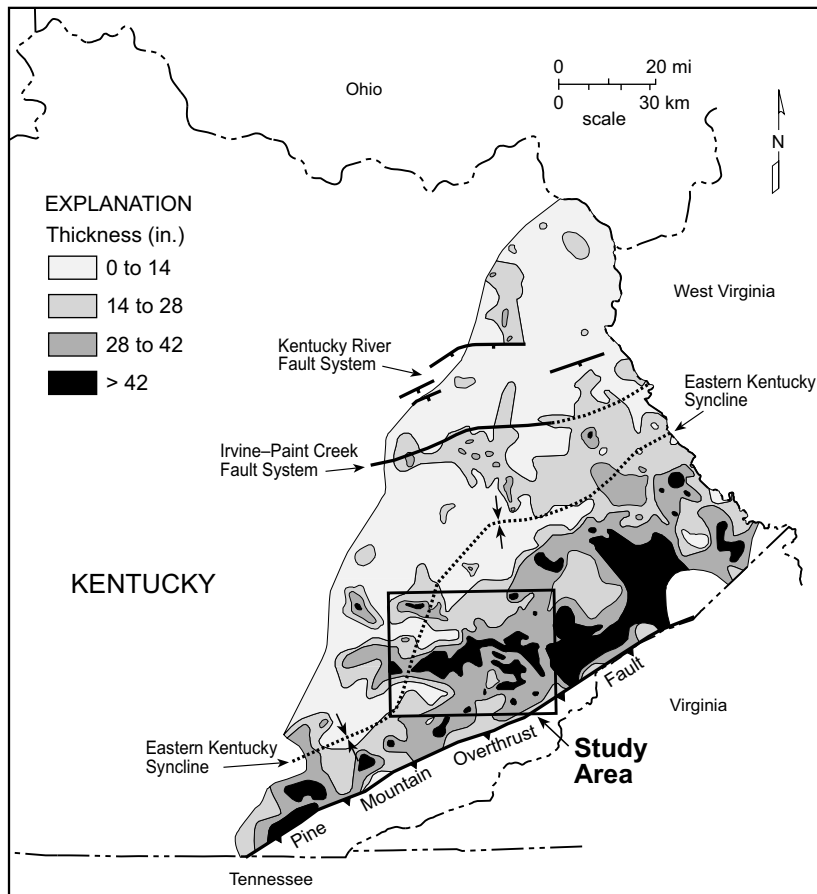


Figure 3. Thickness of the Fire Clay coal in the Eastern Kentucky Coal Field (after Brant, 1983a, b; Brant and others, 1983a–d). Locations of major structures after Haney and others (1983).

and Minerals. The approximate boundaries of surface mines were digitized from copies of hand-drawn permit maps obtained from the Kentucky Department of Surface Mining Reclamation and Enforcement. Contacts of areas of reduced coal thickness (that is, rolls and cutouts), derived from notations on mine maps and conversations with mine personnel, were also digitized.

Point-Source Data

Coal-thickness measurements were the major point-source data used in this study. Coal thicknesses were obtained from the Kentucky Geological Survey's Kentucky Coal Resources Information System, pillar measurements from mine maps, outcrop measurements from along roads and mine highwalls, and subsurface core records provided by mining companies. More than 3,800 thickness points were used in this study. Additional confidential thickness measurements were examined in order to determine the presence or absence of coal in certain areas, but their locations were not plotted. Besides the coal-thickness data, the locations of oil and gas wells that penetrated the coal were obtained from the Kentucky Geological Survey's Office of Geologic Information; these locations were used to calculate areas of restrictions to mining.

DATA PREPARATION

Vector-Line and Map Data

Vector-line and map data are lines on a map that represent a particular value or limit (for example, limit of a coal, elevation lines, etc.). Various types of map and vector-line data were digitized using the program GSMAP (version 7.2; Selner and Taylor, 1991). The outcrop of the Fire Clay coal was digitized from stable-base Mylar geologic maps of the 15 quadrangles that make up the study area (Puffett, 1964, 1965a, b; Seiders, 1964, 1965; Danilchik and Lewis, 1965; Mixon, 1965; Prostka, 1965; Prostka and Seiders, 1968; Danilchik, 1976; Maughan, 1976; Waldrop, 1976; Ping, 1977; Lewis, 1978; Taylor, 1978). Locations of roads, towns, airports, cemeteries, streams, power lines, railroads, and parks were digitized from the topographic maps of the 15 quadrangles. The approximate boundaries of underground mines were digitized from copies of hand-drawn mine maps obtained from the Kentucky Department of Mines

RESTRICTIONS TO MINING

Most land-use restrictions are outlined under the Kentucky Natural Resources and Environmental Protection Cabinet's document 405 KAR (Kentucky Administrative Regulations) 24:040, entitled "Areas Unsuitable for Mining." This document relates to Kentucky Revised Statutes 350.465(2)(b) and 350.610, which define the regulatory program for surface mining in Kentucky. Land-use restrictions can apply to both surface- and deep-mineable coals, as shown in Table 1, but we followed the practice of previous availability studies (for example, Andrews and others, 1994), and applied them only to areas of potentially surface-mineable Fire Clay coal. Except for federally funded highways, nationally protected lands, and cemeteries, variances are often granted for many of the restrictions listed in the regulations.

Technological restrictions apply to potentially deep-mineable coals. These restrictions include barriers around existing underground mines and existing oil and

Table 1. Potential restrictions with applicable buffer zones and overburden categories to which they apply.

	<i>Restrictions</i>	<i>Buffer</i>	<i>Mine Category</i>	
			<i>Surface</i>	<i>Deep</i>
<i>Land-use</i>	Airports	area + 100'	X	X
	Bridges	area + 100'	X	
	Cemeteries	area + 100'	X	
	Faults	area + 100'	X	X
	Oil & gas wells	200'	X	
	Public lands	area	X	X
	Pipelines	area + 100'	X	
	Power lines	area + 100'	X	
	Railroads	area + 100'	X	
	Roads	area + 100'	X	
	Streams	area + 100'	X	X
	Parks, National	area	X	
	Parks, State	area	X	
	Municipalities	area + 300'	X	X
<i>Technological</i>	Coal too thin	area		X
	Coal too deep	area		X
	Faults	area + 100'		X
	Interburden < 40'	area		X
	Mine barriers	50'		X
	Mining within 40'	area		X
	Oil & gas wells	200'		X

gas wells, and coal too thin (less than 28 in. thick) to be profitably mined by current underground mining methods (Table 1). In the study area, none of the Fire Clay coal was considered too deep for mining. Also, the interburden (strata between mined coals) restriction was not a factor because all of the known areas where the Fire Clay rider coal was being mined were where the Fire Clay coal was too thin to mine underground (an interburden restriction means that mined coals must be at least 40 ft apart vertically).

Oil and gas wells are restrictions in both the deep- and surface-mineable categories. This is not a duplication of restrictions because oil and gas wells with less than 100 ft of cover are considered land-use restrictions and oil and gas wells with more than 100 ft of cover are considered technological restrictions.

DATA ANALYSIS

The GIS software used for this project was Geographical Resources Analysis Support System (GRASS), a U.S. government software package developed primarily by the U.S. Army Corps of Engineers, the Natural Resources Conservation Service (formerly the U.S. Soil Conservation Service), and the U.S. Geological Survey (U.S. Army Corps of Engineers Construction and Engineering Re-

search Laboratory, 1991). GRASS is a raster-based GIS, which means that the map data are rendered as matrices of equal-size grid cells. Maps stored in a GRASS database must be oriented to a particular coordinate system. The universal transverse Mercator system, based on the Clark 1866 spheroid, was chosen for this study so that it would be oriented similarly to other coal-availability studies in Kentucky. In order to use map information for calculations, the original vector data (lines or areas) are converted to raster (gridded) data files. Because this study covered such a large region, a grid cell size of 30 m was chosen for resolution. Table 2 shows methods used to analyze different types of data that were used to generate maps.

Thickness between data points was interpolated using the "s.surf.tps" algorithm. It has a segmentation procedure that enhances the efficiency of mapping for large data sets. Parameters are computed directly from the interpolation function so that the important relationships between these parameters are preserved. The algorithm interpolates the values of point data to grid cells and computes analysis from given site data to GRASS raster format using a process called "spline with tension" (U.S. Army Corps of Engineers Construction and Engineering Research Laboratory, 1991).

<i>Map Type</i>	<i>Data Source</i>	<i>Method of Generating GRASS Cell</i>	<i>Resolution</i>	<i>Comments</i>
Map boundaries	corner points		30 m	used as data mask
Outcrop	1:24,000 USGS GQ's	digitized	30 m	used for original resource maps
Mines	Ky. Dept. of Mines & Minerals/Dept. of Surface Mines	digitized	30 m	used for remaining resource calculations
Land-use restrictions	1:24,000 topographic maps	digitized	30 m	used for available resource calculations
Oil & gas well data	KGS Office of Geologic Information	s.poly output	30 m	restriction
Reliability arcs	Derived from thickness locations	s.poly output	30 m	reliability categories
Thickness isopach	KCRIS*, core data, mine maps, and others	s.surf.tps	30 m	used for thickness maps and resource calculations

*Kentucky Coal Resources Information System

Tonnage Estimates

Once all maps were prepared, the U.S. Geological Survey program RESOURCES was used to calculate areas (in square meters) of all resource categories (original, mined-out, remaining, restricted, and available). Using the following definitions, these data were then converted to acres, and tons of resources were calculated:

1 acre=4,047 m²

1 acre-foot of bituminous coal=1,800 short tons

Resource Categories. Tonnage estimates for each bed were reported by the categories of coal thickness, overburden thickness, and reliability. Standard U.S. Geological Survey procedures (Wood and others, 1983) stipulate thickness categories in multiples of 14 in. up to 42 in., and multiples of 42 in. up to 168 in. Thicknesses greater than 168 in. are aggregated. For this study, 14-to-28-in., 28-to-42-in., 42-to-56-in., and greater-than-56-in. categories were used. Coal less than 28 in. thick is not generally mined underground in Kentucky because of technological and economic considerations.

Overburden Categories. Overburden categories are delineated according to potential mining method. Three categories are defined: surface mineable, deep mineable, and coal too deep or thin to mine with current technology. In practice, the thicknesses for each of these categories can vary depending on topographic relief, seam and interburden thickness, quality of the coal being mined, and the market to which the coal is being sold. In general, however, 100 ft of overburden is a reason-

able maximum for surface mining of the Fire Clay coal, and 1,000 ft of overburden for underground mining. Few, if any, surface mines in the Fire Clay coal with more than 100 ft of overburden have been developed, and no deep mines have been developed in the coal in areas with more than 1,000 ft of overburden. In fact, the Fire Clay coal is less than 1,000 ft from the surface throughout the study area, making the too-deep-to-mine category unnecessary.

Reliability Categories. In any quantitative analysis, the results are only as good as the supporting data. Across broad areas, the density of data greatly affects the accuracy of thickness interpolations. Reliability categories, which are based on the distance to a known data point, are used to define the density of data points for coal-resource studies. "Measured" resources occur within 0.25 mi of a data point (known coal thickness), "indicated" resources between 0.25 and 0.75 mi, "inferred" resources between 0.75 and 3 mi, and "hypothetical" resources beyond 3 mi. The most reliable category is "measured," whereas the least reliable is "hypothetical." Figure 4 shows the locations of data points used in this study. Approximately 125,000 acres, or 35.0 percent of the study area, fall in the measured category; 138,000 acres, or 38.7 percent of the study area, fall in the indicated category; and 94,000 acres, or 26.3 percent of the study area, fall in the inferred category. The greatest density of data is in the mined areas in the Hyden West, Hyden East, Hazard South, Vicco, and Blackey quadrangles. This is the region of thickest and most uni-

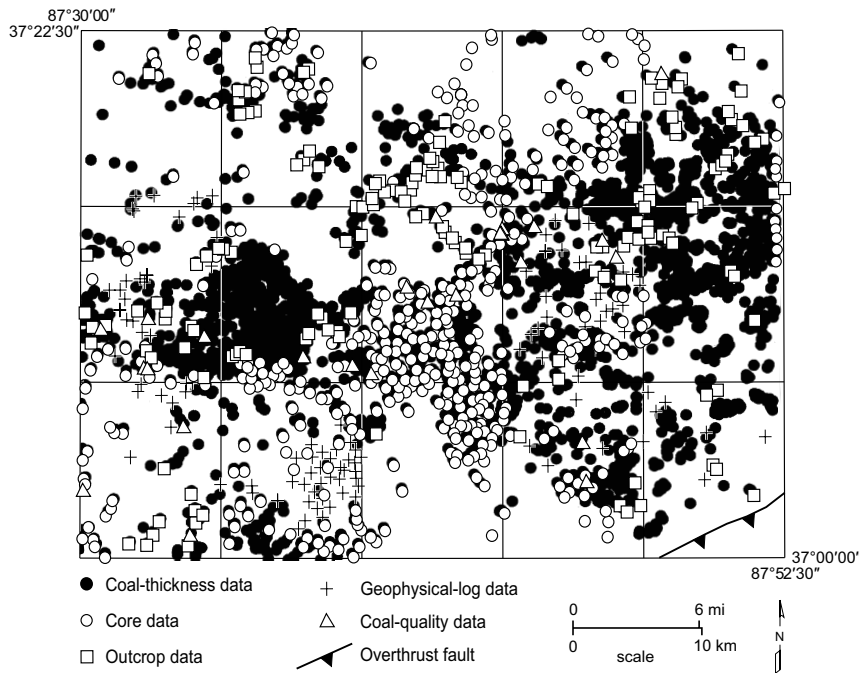


Figure 4. Locations of thickness data used in this study.

form coal conditions, and in this area most of the data fall in the measured or indicated categories.

RESULTS

Original Resources

Original coal resources are estimates of the total amount of coal greater than 14 in. thick that existed prior to mining. The 14-in. limit was chosen because thinner coal is not generally mined. The original thickness distribution of the resource is shown in Figure 5. Trends of coal thickness are discussed in Greb and others (1999). Trends in quality across part of the area are discussed in Eble and others (1999). The tonnages of coal in terms of depth, thickness, and reliability are shown in Table 3. The total original resource we calculated for the Fire Clay coal in the study area is 1.76 BT. The previous estimate for the Fire Clay coal for this area was 1.71 BT (Table 4). More data points were available for the present study, which resulted in greater measured and indicated resources, and fewer inferred resources (Table 4). Although the total differences between the current estimate and the previous estimate are small, the present study found significantly less coal greater than 42 in. thick than the previous study (Table 4).

Mined-Out and Remaining Resources

Mined-out tonnages were measured from maps of approximate mine limits, and estimated coal thicknesses were interpolated from discrete coal-thickness measure-

ments within and around mines. Coal production data were not used because the data could not be correlated to specific mines and map areas, and because these data do not account for coal lost in mining (pillars, barriers, etc.). Figure 6 shows the approximate areas of mined coal. We estimate the total tonnage of Fire Clay coal mined in the 15-quadrangle area at 449 MT, or 26 percent of the original estimate. Subtracting the total tonnage of coal mined from the original resource yields a remaining resource of 1.3 BT for the study area. Table 5 illustrates the remaining resource in terms of depth, thickness, and reliability. Figure 7, a map of the remaining coal, indicates that most of the mined coal has been greater than 42 in. thick.

Available Resources

Available resources are estimated by subtracting restrictions to mining from remaining resources. Land-use restrictions occur across the study area, and are estimated at 9 MT, or less than 1 percent of the remaining resource (Fig. 8). Technological restrictions are concentrated in the northwestern part of the study area where the coal is less than 28 inches thick across large areas (Fig. 7); they are estimated at 391 MT, or 30 percent of the remaining coal (Fig. 8). Of the technologically restricted coal, coal from 14 to 28 in. thick accounts for 334.3 MT, or 25.5 percent of the remaining coal. In the past 10 years, the Fire Clay coal has not been mined underground where it is less than 28 in. thick, so with present technology this appears to be a realistic technological limit. Only one coal in Kentucky, the Blue Gem coal, is extensively mined underground where it is less than 28 in. thick. It has unique quality characteristics, however, that justify its mining.

Subtracting the restrictions from the remaining coal yields available coal resources of 911 MT (Fig. 9). An analysis of the coal available for deep and surface mining (Table 6) shows that 856 MT, or 65.3 percent of the remaining coal, is available for deep mining, whereas only 55 MT, or 4.2 percent of the remaining coal, is available for surface mining (Fig. 10). This is because most of the surface resources of Fire Clay coal have already been mined in the study area. Most of the coal available for deep mining (80.03 percent) is in the 28-to-42-in. category; less than 15 percent of the coal available for deep mining is greater than 42 in. thick.

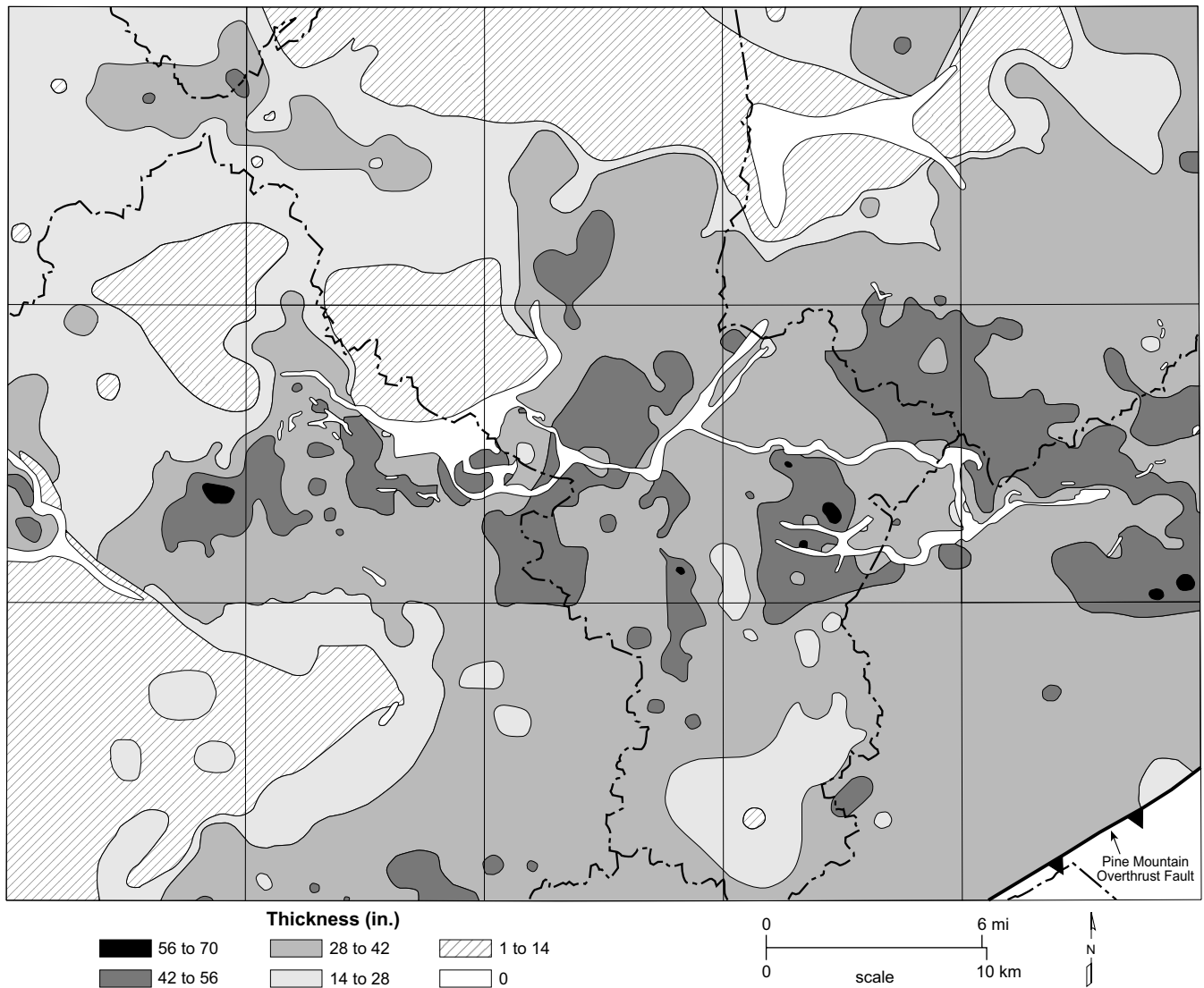


Figure 5. Original Fire Clay resources in the study area.

Areas of Available Coal Resources

Figure 10 illustrates the available coal in the study area. Coal greater than 42 in. thick remains in the Vicco, Hazard South, Cutshin, Leatherwood, and Tilford quadrangles, and in each area is currently being mined.

Areas of 28-to-42-in. coal are more widespread. Small blocks of coal located on the margins of areas of previous mining may remain in the Buckhorn, Krypton, Hyden West, Hyden East, Cutshin, and Carrie quadrangles. In these areas mining typically ceased because of poor roof conditions (often caused by riders near the top of the coal) or variable coal thickness, characteristics typical of the outer margins of the Fire Clay coal in the western part of the study area (Greb and others, 1999). Simi-

lar conditions should be expected in the unmined parts of these areas.

The largest region of Fire Clay coal estimated to be available for future mining is in the Leatherwood and southern Tilford quadrangles (Fig. 10). Publicly available data for this region are mostly in the inferred reliability category. The coal occurs within an elongate trend believed to be characterized by variable coal thickness and roof conditions, however. Local areas of coal thicker than 42 in. may occur where riders merge with the main coal bed (Greb and others, 1999). Cutouts and reduced bed height beneath sandstone roofs may occur. Also, the available coal in the Leatherwood and Tilford quadrangles is significantly distant from surface access and major transportation routes.

Table 3. Estimated tonnages (MT) of original Fire Clay coal in the study area by depth, thickness, and reliability categories.

		Reliability Categories			Total	% of Total Original
		Measured	Indicated	Inferred		
Deep-Mineable (> 100 ft cover)	> 56 in.	3.34	1.30	0.00	4.64	0.26
	42–56 in.	156.11	112.49	15.56	284.16	16.14
	28–42 in.	418.61	394.59	223.08	1,036.28	58.84
	14–28 in.	61.85	141.51	148.55	351.91	19.98
	Total	639.91	649.89	387.19	1,676.99	95.23
Surface-Mineable (< 100 ft cover)	> 56 in.	0.13	0.00	0.00	0.13	< 0.01
	42–56 in.	10.59	5.58	0.72	16.89	0.96
	28–42 in.	27.75	18.23	5.67	51.65	2.93
	14–28 in.	4.08	5.90	5.41	15.39	0.87
	Total	42.55	29.71	11.80	84.06	4.77
Grand total: 1,761.05						

Table 4. Comparison of Brant and others' (1983b) estimated tonnages of original Fire Clay coal with this study's estimated tonnages. Values in millions of tons.

Brant and others (1983b)		14–28"	28–42"	42–56"	56–70"	70+"	Total
	Measured	21.26	78.48	77.24	10.03	0.12	187.13
	Indicated	100.13	368.39	237.92	21.35	0	727.79
	Inferred	259.89	446.77	90.84	1.83	0	799.33
	Total	381.28	893.64	406.00	33.21	0.12	1,714.25
This study		14–28"	28–42"	42–56"	56+"		Total
	Measured	65.93	446.36	166.70	3.47		682.46
	Indicated	147.41	412.82	118.07	1.30		679.60
	Inferred	153.96	228.75	16.28	0		398.99
	Total	367.30	1,087.93	301.05	4.77		1,761.05
□ = Demonstrated reserves							
Percent change		14–28"	28–42"	42–56"	56+"		
	Measured	+210%	+469%	+116%	–66%		
	Indicated	+47%	+12%	–50%	–94%		
	Inferred	–41%	–49%	–82%	–100%		
	Total	–4%	+22%	–26%	–86%		
+ = Increase – = Decrease							

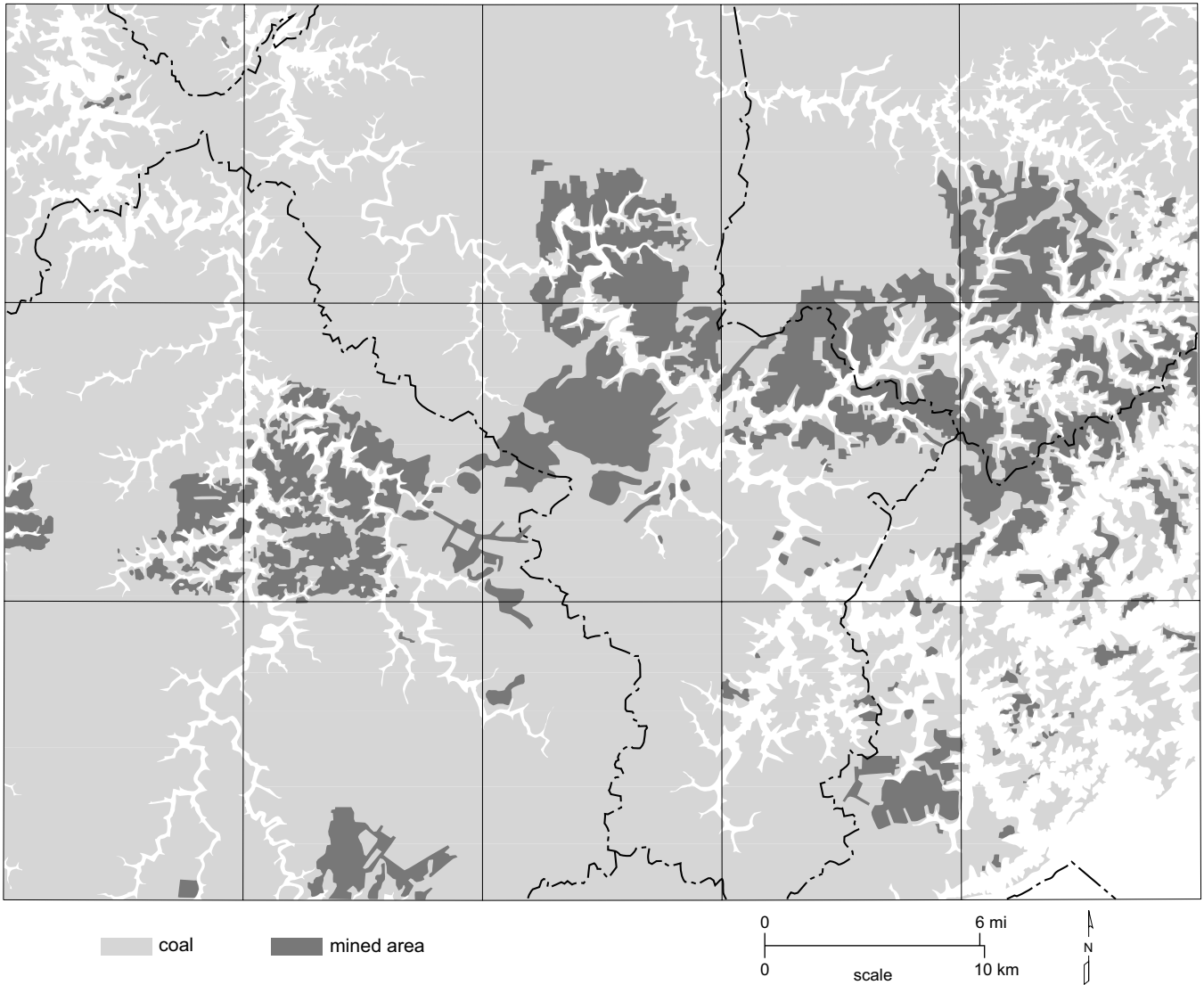


Figure 6. Areas of mined-out Fire Clay coal in the study area.

Table 5. Estimated tonnages (MT) of remaining Fire Clay coal in the study area by depth, thickness, and reliability categories.

		Reliability Categories			Total	% of Total Remaining
		Measured	Indicated	Inferred		
Deep-Mineable (> 100 ft cover)	> 56 in.	1.88	0.66	0.00	2.54	0.19
	42–56 in.	84.05	52.27	1.74	138.06	10.53
	28–42 in.	257.23	309.05	202.97	769.25	58.65
	14–28 in.	54.42	134.54	148.26	337.22	25.71
	Total	397.58	496.52	352.97	1,247.07	95.08
Surface-Mineable (< 100 ft cover)	> 56 in.	0.05	0	0	0.05	< 0.01
	42–56 in.	7.00	3.68	0.35	11.03	0.84
	28–42 in.	19.63	14.12	4.77	38.52	2.94
	14–28 in.	3.74	5.73	5.39	14.86	1.13
	Total	30.42	23.53	10.51	64.46	4.91
Total: 1,311.53						

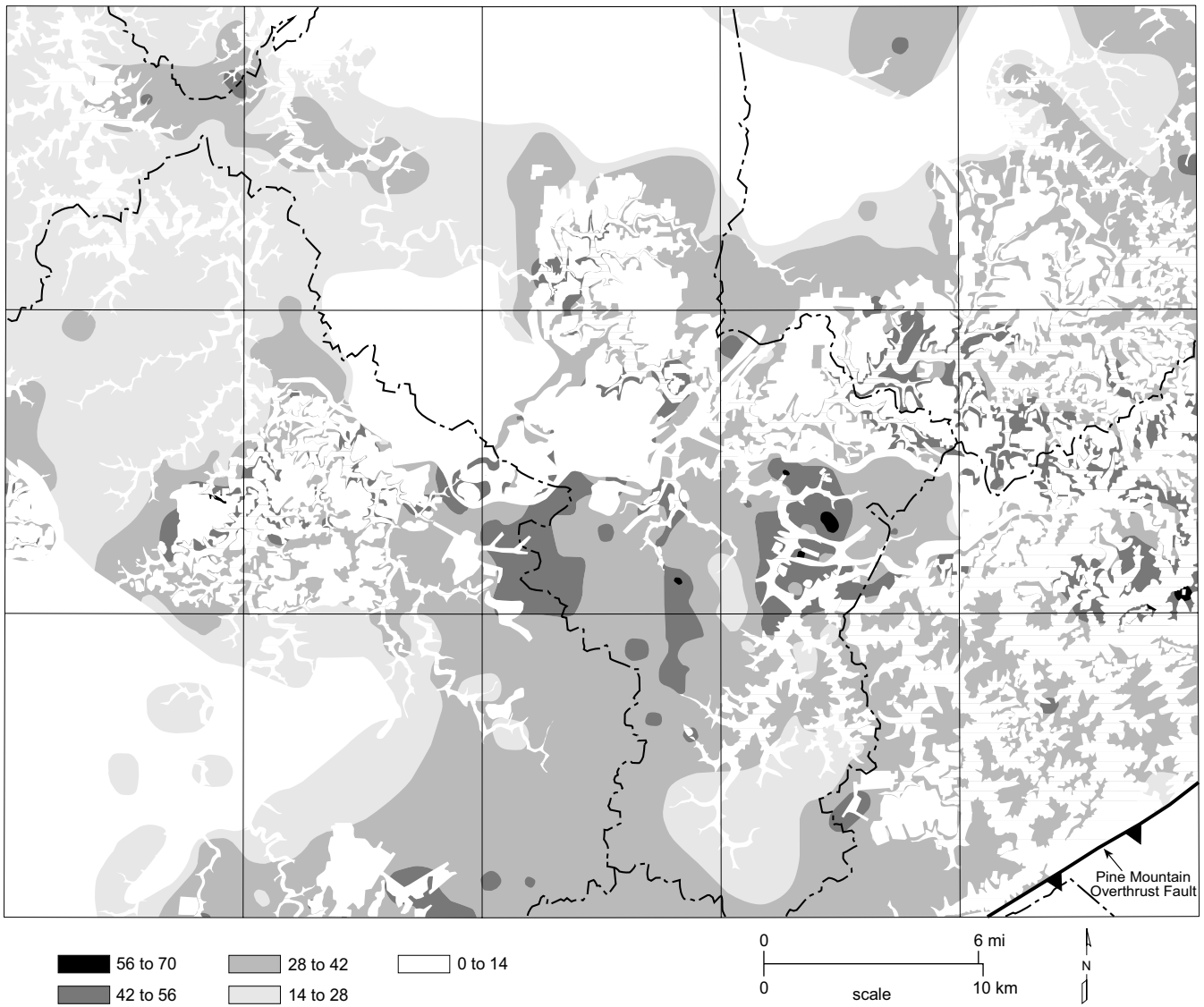


Figure 7. Remaining Fire Clay coal resources in the study area.

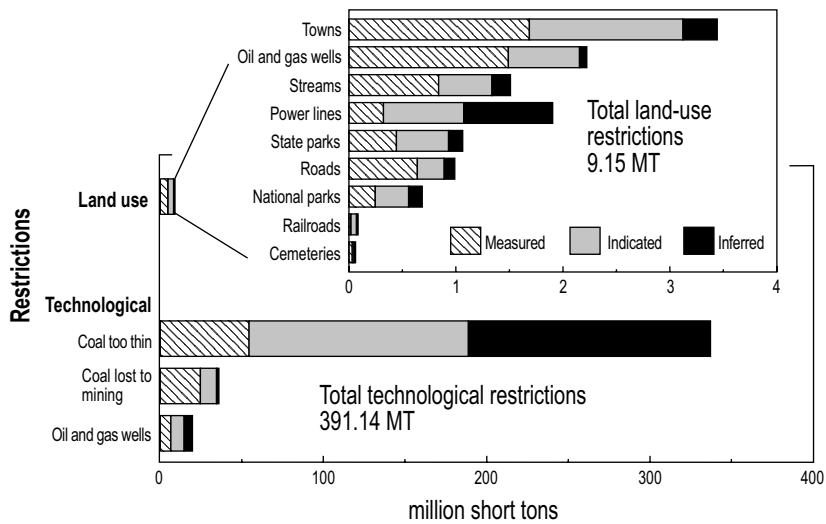


Figure 8. Types and amounts of land-use and technological restrictions in the study area.

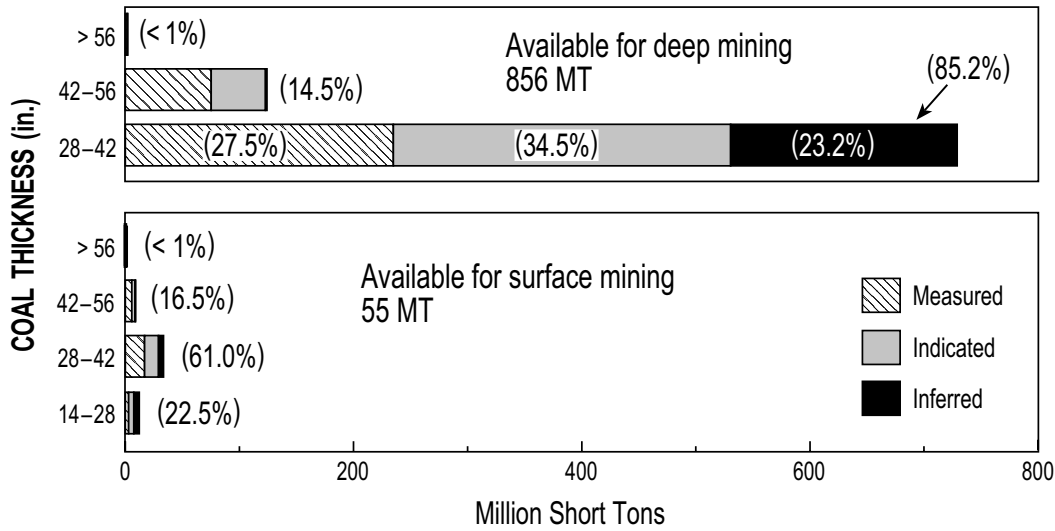


Figure 9. Tonnes of Fire Clay coal available for deep and surface mining in the study area.

HISTORICAL PERSPECTIVE

Trends in recent Fire Clay coal mining may relate to the availability of coal in the region. In 1982, 136 mines produced 4.89 MT of Fire Clay coal (Fig. 11). In 1992, 52 mines produced 8.95 MT of the coal (Fig. 11). In general, the increase in production (83 percent) and decrease in number of mines (62 percent) was associated with the increasing size of underground mines in the area.

Throughout the last decade the greatest production has been concentrated in the Hyden West, Hyden East, Hazard South, Vicco, and Blackey quadrangles (Fig. 12). Figure 5 shows that this is the region where the coal is

thickest. In western quadrangles, the coal thins or becomes extremely variable in thickness. In these areas, production has decreased through the last 10 years, and in six quadrangles has ceased (Fig. 12). By far the most production has come from the Vicco and Blackey quadrangles, both of which are in areas where the coal is thick. Production in the Blackey quadrangle has decreased in recent years because the coal is mostly mined out there (Fig. 6). Some coal is still available in the Vicco quadrangle, and is currently being mined.

Almost all deep mines in the study area have been above-drainage drift mines. The largest areas of available coal are below drainage, however, and not surface

Table 6. Estimated tonnages (MT) of available Fire Clay coal in the study area by depth, thickness, and reliability categories.

		Reliability Categories			Total	% of Total Available
		Measured	Indicated	Inferred		
Deep-Mineable (> 100 ft cover)	> 56 in.	1.69	0.60	0	2.29	0.25
	42-56 in.	75.26	47.69	1.44	124.39	13.65
	28-42 in.	234.98	295.65	198.63	729.26	80.03
	Total	311.93	343.94	200.07	855.94	93.93
Surface-Mineable (< 100 ft cover)	> 56 in.	0.05	0	0	0.05	< 0.01
	42-56 in.	5.82	3.11	0.25	9.18	1.00
	28-42 in.	16.89	12.27	4.51	33.67	3.69
	14-28 in.	3.00	4.61	4.82	12.43	1.36
	Total	25.76	19.99	9.58	55.33	6.06
Grand total: 911.27						

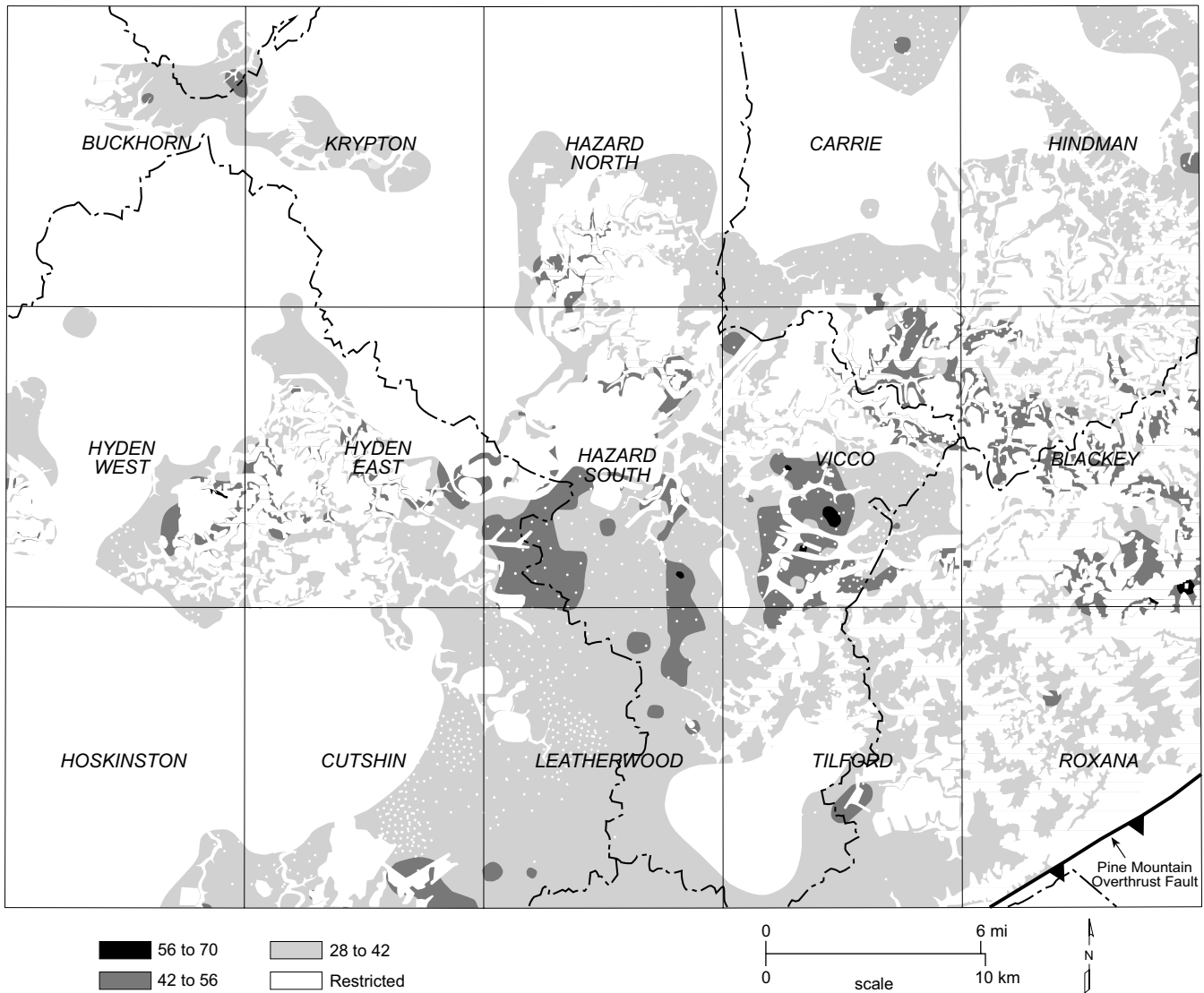


Figure 10. Fire Clay coal available for mining in the study area. Only coal that can be deep mined is shown, because the areas of surface-mineable coal are too small to be seen at this scale.

accessible. As of 1995, a single mine in the Tilford quadrangle is the only slope access to below-drainage coal. The lack of slope and shaft mines in the area is undoubtedly because significant amounts of economically viable coal were available above drainage in the past. As the easily accessible resources are mined out, however, companies who want to mine the Fire Clay coal will need to consider slope or shaft mining in areas where coal may be of variable thickness and associated with variable roof conditions.

Comparison to Previous Studies

Coal-availability studies have been completed for nine 7.5-minute quadrangles in eastern Kentucky and

one quadrangle along the Kentucky-Virginia border (Fig. 13). The results of those studies are summarized in Table 7 and compared with the results of the current study. Comparing multiple coals in single 7.5-minute quadrangles to a single coal in multiple quadrangles is a comparison of apples and oranges, but certain qualitative analogies can still be made.

The single-quadrangle studies show a higher percentage of remaining coal than the Fire Clay coal study. This difference is because many coal beds included in the single-quadrangle studies have not been significantly developed. The Fire Clay study reflects the greater depletion of a major coal resource with a market reputation.

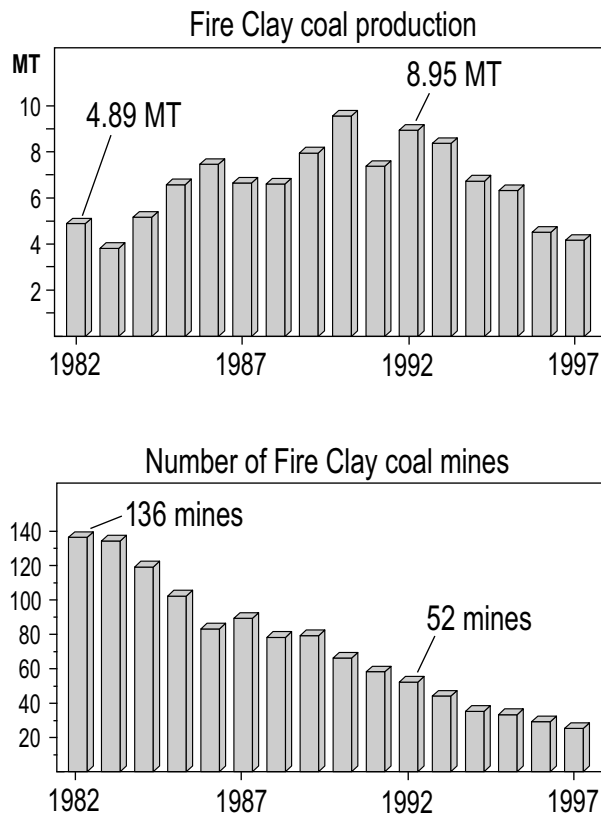


Figure 11. Mining of the Fire Clay coal through the years in the study area.

In both the single-quadrangle and Fire Clay studies, the technological restriction of coal too thin to mine has the most significant impact on available resources. This restriction assumes present technology and market conditions, and may indicate the importance of developing cost-effective thin-seam mining strategies in the future.

Land-use restrictions, which are often a problem for an individual mine, have less impact across a broad area. Part of the reason for this difference is that in eastern Kentucky most coals are mined above drainage. Roads, railroads, oil and gas wells, and other land-use restrictions often follow streams or terraces of streams at or near drainage, and hence are not restrictive to mining higher up on a hillside, above drainage.

The available resource of 911 MT of Fire Clay coal, at 52 percent of the original and 70 percent of the remaining resource, is similar to the percentages of original and remaining resources for multiple coals in any single quadrangle. The similarity indicates that significantly less coal is available for mining than often assumed. A change in technology or markets, however, would cause the amount of available coal for all studies to increase.

The Fire Clay coal study best compares with the Appalachia quadrangle study (Sites and Hostettler, 1991). Both studies estimated approximately 75 percent of coal resources remaining and 52 percent of the remaining resources available. Also, the original resources of 1.35 BT for the Appalachia quadrangle and 1.76 BT for

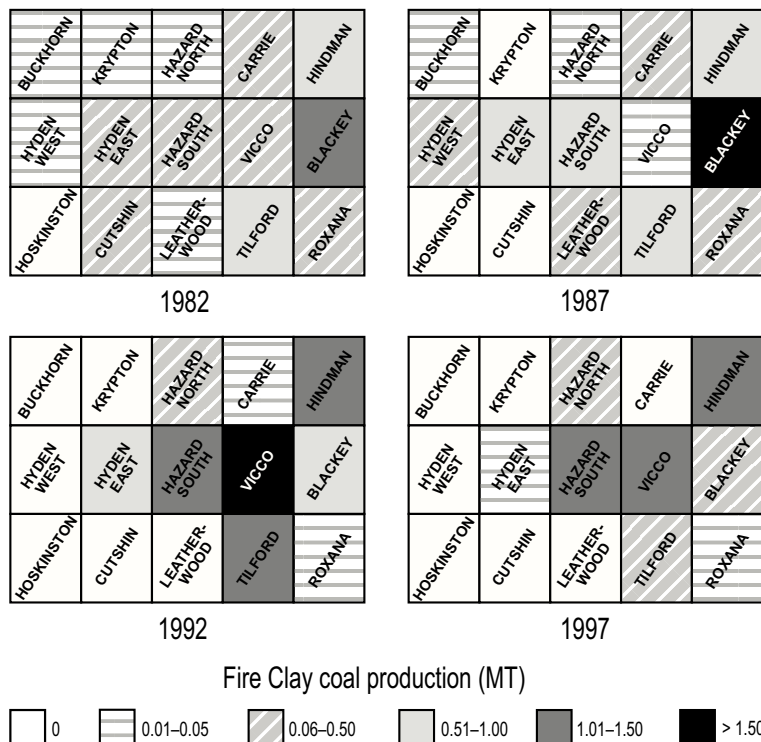


Figure 12. Production of Fire Clay coal by quadrangle in 1982, 1987, 1992, and 1997.

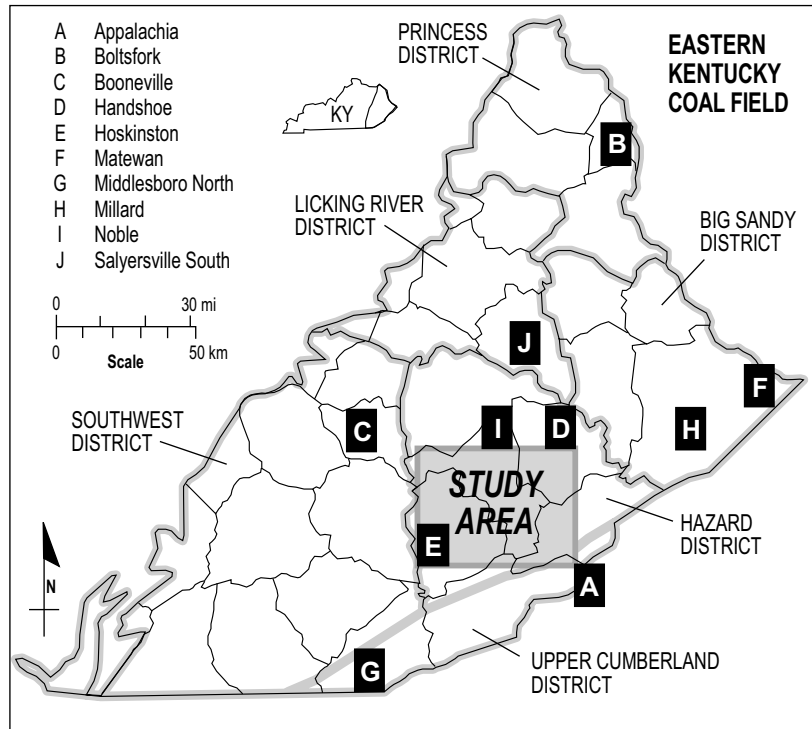


Figure 13. Locations of completed coal-availability studies.

the Fire Clay study are similar, especially when compared with the original resources for the other quadrangles. Both areas are located in the southeastern, deeper part of the central Appalachian Basin, where coal beds are generally thicker and more widespread than in other areas. Both areas have similar topography,

which results in similar land-use restrictions. Also, the similarity of results may suggest that where there are large original resources (whether one bed across a large area, or multiple beds in a small area), there has been more active mining and hence fewer remaining resources.

Table 7. Summary of eastern Kentucky coal-availability studies and current study, giving total tonnages (MT) and proportions. All tonnages and percentages rounded to nearest whole number.

Quadrangle	Key to Fig. 13	Original Resources		Remaining Resources ¹		Land-Use Restrictions ²		Technological Restrictions ²		Available Resources ¹	
		MT	%	MT	%	MT	%	MT	%	MT	%
Appalachia ³	A	1,349	100%	1,005	74%	26	3%	277	28%	702	52%
Boltsfork ⁴ †	B	243	100%	231	95%	15	6%	43	19%	173	71%
Booneville ⁵	C	80	100%	70	88%	1	1%	29	41%	40	50%
Handshoe ⁶	D	645	100%	633	98%	10	2%	220	35%	403	62%
Hoskinston ⁷ †	E	342	100%	332	97%	19	6%	171	52%	142	42%
Matewan ⁸	F	987	100%	858	87%	17	2%	226	26%	615	62%
Middlesboro North ⁹	G	339	100%	328	97%	36	11%	138	42%	154	45%
Millard ¹⁰ †	H	843	100%	777	92%	30	4%	400	51%	347	41%
Noble ¹¹ †	I	460	100%	399	87%	58	15%	71	18%	270	59%
Salyersville South ¹²	J	183	100%	160	87%	13	8%	66	41%	81	44%
This study		1,761	100%	1,312	75%	9	< 1%	391	30%	912	52%

†Results updated in 1993

¹Percentage of original

²Percentage of remaining

³Sites and Hostettler (1991)

⁴Anderson and others (1991)

⁵Weisenfluh and others (1992)

⁶Weisenfluh and others (1993)

⁷Davidson and others (1991)

⁸Carter and Gardner (1989)

⁹Kentucky Geological Survey (1990)

¹⁰Sergeant and others (1989)

¹¹Sergeant and others (1988)

¹²Andrews and others (1994)

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